

Orbit

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Celebrating 50 Years of Bently Nevada™ Products

- Runout – How to Spot it, How to Correct it
- Case History – Improving Reliability at Mirant Philippines
- Clean Sound – A How-To Guide for Monitoring Sonic Horns
- First Look – A New Platform for Modeling, Optimization, and Control
- Looking Forward – The View from the GM

Orbit

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Practice of Operating Asset Condition
Monitoring, Diagnostics, and
Performance Optimization

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EDITOR'S NOTE

50 candles, 50 years of progress

Don Bently originally encountered eddy current technology while attending graduate school and working as a controls engineer in the aerospace industry. His employer at that time didn't really think the technology had a future, so he told Don it was all his (I'll bet he's kicking himself now). That was 1955. Don stepped out and started his own business, building proximity probes from his garage and selling them via mail order.

Entrepreneurs are noted for their passion, and Don certainly had – and continues to have – plenty of that, but I'm not sure in those early days that Don had a clear picture of where proximity probes would ultimately find their most useful application. He had cool technology. Now, he just needed the right problem to solve.

The answer came in the early 1960s when machinery manufacturers began discovering these devices. Proximity probes solved a long-standing problem: they allowed users to see what was happening inside their machinery, rather than inferring it from looking only at the outside. Don had finally found his "killer application" – the one that would propel his probes from a little more than a mail order novelty to a mainstream measurement for virtually all industrial turbomachinery.

The rest, as they say, is history. This month marks the 50th birthday of a remarkable journey that continues to this day.

During the last half century, the Bently Nevada™ product line has come a long way. Today, there are several thousand products in the catalog – not just the dozen or so offerings of 50 years ago. And the original expertise as an instrument manufacturer has grown to encompass machinery diagnostics and rotor dynamics as well. In 2002, Bently Nevada was acquired by GE Energy and now operates as part of a larger portfolio of complementary optimization and diagnostic offerings – many of which we've begun featuring in ORBIT.

As the journey continues, you can rest assured that the condition monitoring solutions for which the Bently Nevada name is best known are alive and well. We continue to develop and introduce products at a feverish pace, in order to stay ahead of your growing needs. And we have every intention of celebrating a milestone like this one in another 50 years. Thanks for your continued support. We're proud of the trust you've shown us over the years with your business, and we work hard every day to continue earning that trust.





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- Oil Analysis 101 – Part II

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THE COLOR OF RUNOUT

17-4 PH stainless steel as seen under polarizing light at 50X magnification. The colors show martensite matrix formations and delta-ferrite with copper precipitates – all of which contribute to the material's tendency toward high levels of electrical runout.

Understanding and Mitigating Shaft Runout

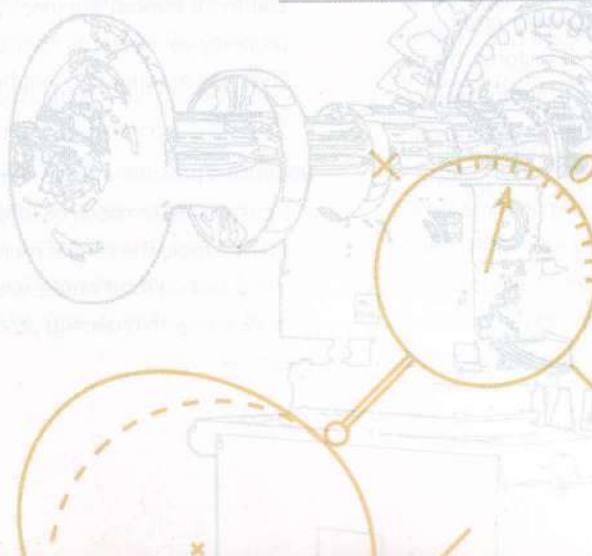
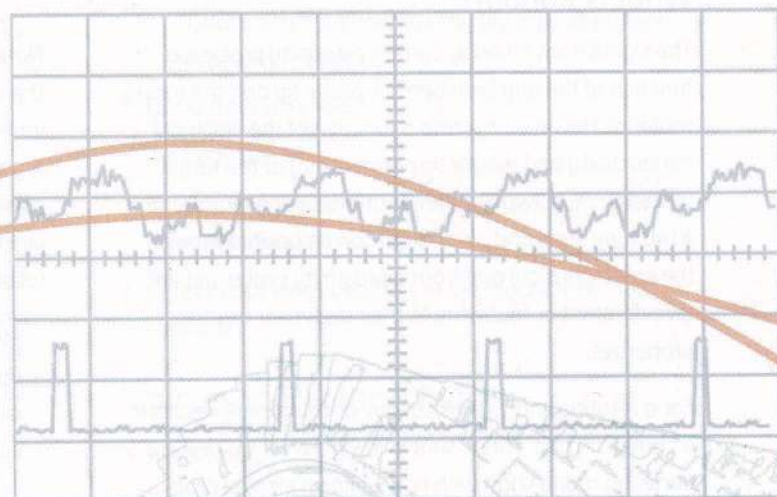
Introduction

This article explains what runout is, why it is important, and the root causes of runout in machinery shafts. It also outlines common methods for reducing runout to allowable levels and suggests best practices to observe during fabrication and machining to help avoid runout difficulties in the first place. While there is no

guarantee that runout can be mitigated or prevented in every application, it can be managed effectively and kept to within allowable levels in the vast majority of applications. This is evidenced by the millions of successful proximity probe applications for turbomachinery around the world over the past forty years.

Nathan Littrell

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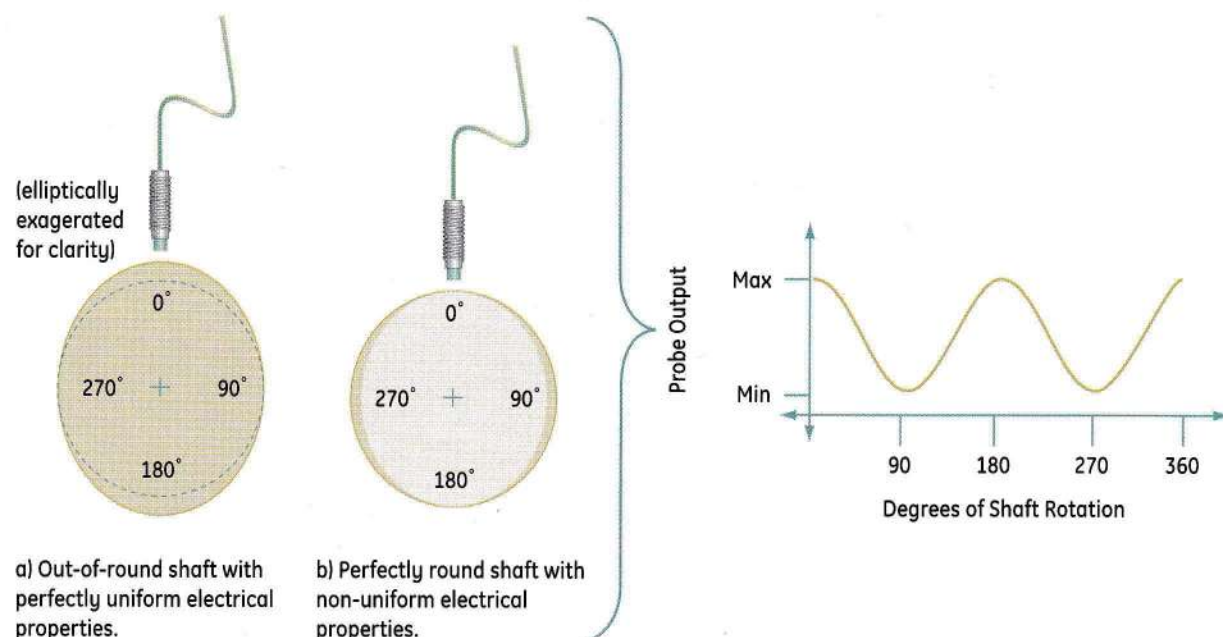


Figure 1 – “Apparent” probe gap for a) an out-of-round shaft with uniform electrical properties and b) a perfectly round shaft with non-uniform electrical properties.

What is Runout?

The signal from an eddy current proximity probe is a function of the gap between the probe tip and the target material. However, it is also a function of the electrical conductivity and magnetic permeability of the target material. Thus, two different materials (for example, 4140 type steel and aluminum) can be positioned with the same physical gap from a proximity probe, yet will give different outputs due to their dissimilar electrical properties.

For a rotating shaft, physical out-of-roundness results in a change in gap. This is shown in Figure 1a. However, a perfectly round shaft with non-uniform electro-magnetic properties will also result in a change in probe output, even though the physical gap is uniform. This is shown in Figure 1b. In this example, both shafts give identical probe outputs even though they have different physical shapes. In practice, mechanical runout can indeed be somewhat sinusoidal as shown in the example. However, electrical runout is rarely – if ever – sinusoidal and is generally characterized by a noisy waveform with numerous spikes. It is represented as a sinusoid in this example merely for illustrative purposes.

Notice also that these signals have nothing to do with the dynamic motion or vibration of the shaft. They are inherent properties of the shaft that will be observed regardless of whether it is stationary or rotating at high speed. These signals are known as runout. For convenience, we divide runout into two primary categories as follows:

Mechanical Runout is a measure of the shaft's deviation from a perfectly uniform radius as its circumference is traversed. This type of runout can be measured by a dial indicator.

Electrical Runout is a measure of a shaft's electrical property variations as its circumference is traversed. This type of runout cannot be measured by a dial indicator.

Because a proximity probe senses both types of runout, it is customary to speak of **Total Indicated Runout (TIR)** which is simply the sum of mechanical runout and electrical runout. In most cases, when runout is discussed in conjunction with proximity probes, it is understood to mean TIR.

BECAUSE THE RUNOUT SIGNAL IS NOT RELATED TO ACTUAL SHAFT VIBRATION, IT CAN LEAD TO ERRONEOUS VIBRATION READINGS AND MACHINERY DIAGNOSTIC CONCLUSIONS.

Why Be Concerned About Runout?

Even if a target material has non-uniform physical or electrical properties, it does not create a problem for probes observing the same location on the target at all times – such as an axial position measurement using the end of a shaft. However, proximity probes are often used for radial vibration measurements where the “track” observed by the probe is constantly changing (repeating itself every 360 degrees) as the shaft rotates. This results in a proximity probe signal composed of both actual vibration and runout. Because the runout signal is not related to actual shaft vibration, it can lead to erroneous vibration readings and machinery diagnostic conclusions. To avoid this problem, the amount of TIR must be kept to allowable levels, generally 25% or less of expected vibration amplitudes.

Many customers specify the amount of allowable runout for new or refurbished rotors as part of their purchasing documentation to their vendors. American Petroleum Institute (API) Standard 612 is one such frequently cited specification. It pertains specifically to mechanical drive steam turbines and requires the TIR to be 0.25 mil pp or 25% of allowable vibration, whichever is greater. API 617 has identical runout requirements and pertains to process centrifugal and axial compressors as well as turbo-expanders. Similar API standards exist for other machine types.

Failure to meet runout specifications can cause expensive delays and re-work, impacting both the customer and their machinery supplier. For this reason, discovering and correcting electrical runout issues early in the manufacturing process can save a great deal of cost. It is much easier to treat the problem when the shaft is on blocks or mounted on a lathe than when installed in the machine.

Sources of Mechanical Runout

- Machining processes
 - So-called “lobing” of the shaft (see Figures 2 and 3). This is particularly problematic when centerless grinding machines are used because variations in shaft hardness can result in a non-circular geometry. Grinding on centers provides a reference for the wheel to work against and is less prone to runout.
 - Tool chatter. Selection of the correct tool and holder, as well as adjustment, is critical for all machining processes. Make certain tools are not dull.
 - Improper feed rate and speed of cutting tools. Surface finish is strongly affected by cutting tool feeds and speeds.
- Dents from handling
- Rust patches
- Rotor bow due to thermal effects, gravity, or other influences/loads
- Defective or worn bearings in the machine or lathe supports

Sources of Electrical Runout

• Metallurgy

The material chemical composition is fundamental to its electrical and magnetic properties. As well, the material's purity can affect runout. In general, non-ferrous materials such as copper and aluminum exhibit the fewest electrical runout problems, since they are devoid of any significant magnetic effects.

Conversely, the worst materials in terms of electrical runout are precipitation-hardened steels. Precipitation hardening is a process where clumps of different crystal states are formed in the matrix of the parent metal. The

probe observes these clumps as they pass by while the shaft rotates, producing the unwanted runout signal. 17-4 PH can be particularly troublesome in this regard (see photo on page 4).

Bently Nevada™ Proximitor® sensors are calibrated to AISI 4140 type steel. However, this material is available in several grades, and variations in probe system response will vary among these grades. In general, the vacuum arc remelt (VAR) or double vacuum arc remelt (DVAR) materials possess the best homogeneity and exhibit the fewest number of problems with electrical runout.

It is recognized that the choice of shaft materials is rarely as simple as merely considering the material's runout properties. Instead, designers are faced with multiple criteria and inevitable tradeoffs. Pumps are a good example of machines that must often employ more exotic materials due to the corrosive nature of the process fluid that will be handled, whether seawater, liquefied sulfur, acids, or others. Motors are another machine type that commonly use materials other than 4140 type steels. As will be discussed later, when a designer requires certain shaft metallurgies, yet the material exhibits intractable runout characteristics, one approach is to attach a collar or coating of a different material to the shaft.

• Forging

The forging process involves forming an ingot into the rough shape of the shaft using enormous hydraulic hammers and presses. During the forging process, the material flows into the shape of the shaft and gains a grain structure that is present throughout the cross section of the material. This grain structure defines a set of large scale boundaries that contain the smaller scale crystal boundaries. A non-uniform grain structure can result in electrical runout.

• Heat Treatment

The purpose of heat treatment is to modify the crystal structure of a material to tailor the material mechanical properties (toughness, ductility, etc.) to the application. The magnetic properties of ferrous materials are a function of the crystal structure, so it follows that heat treatment is a factor in the resulting electrical uniformity of the shaft.

Many large shafts are quenched as part of the heat treatment process by lowering into tanks of salt water or other liquids. Most commonly, the shaft is horizontal when lowered into the quench tank, which results in an asymmetrical quench profile. It is recommended to lower the shaft vertically into the quench tank if possible to improve the radial homogeneity of the quench.

• Grinding

Grinding the bearing journals to final dimensions and finish is generally the last step in the shaft manufacturing process. The grinding process generates significant heat that is localized at the point where the grinding wheel touches the shaft. It is important to have maximum coolant flow on the work piece and to start and stop the grinding process slowly. Avoid sudden increases or decreases in feed rate when grinding. It is also recommended to keep the wheel freshly dressed to limit heat build up. Because grinding results are highly dependent on the operator, it is recommended that this step be closely monitored if runout problems are occurring.

• Magnetism

Residual magnetic fields in the shaft can cause significant variation in the output of the proximity probe system. Degaussing (discussed later in this article) is the recommended remedy.

• Stress Effects

Stress affects the crystal structure and magnetic properties of materials. Occasionally, a shaft with runout problems can be traced back to an event that caused the probe area to undergo significant mechanical stress. It is best practice to support shafts in slings in such a way that they are not subject to significant bending stresses during installation and handling. Bead blasting or other impact-based cleaning processes create compressive stress in the surface of the shaft and can induce runout.

• Handling

In addition to the stress effects mentioned above, it is possible to 'bruise' metal by hitting or dropping the shaft on the probe tracks during intermediate steps of manufacture. The external damage is erased by subsequent steps such as machining, but the damage to the crystal structure may go quite deep into the material. Thus, it is important to handle the shaft carefully at all steps in the process.

• Plating

Occasionally, a rotor is refurbished by plating the bearing journal area to replace worn material. Sometimes, this surface will be intentionally "roughed up" to allow the chrome plating to adhere better. However, the probe will "see through" the plating to the rough surface underneath, resulting in runout. Also, chrome plating has very different electrical properties than typical shaft materials and strongly affects proximity probe output. In general, plating in the area of proximity probes is not recommended. However, when this is not an option, plating thickness should be at least 20 mils to prevent the "see through" effect mentioned above, and the Proximitor® sensor should be calibrated to the plating material rather than the substrate shaft metallurgy.

Measuring Mechanical Runout

The first step in dealing with runout is to make an accurate measurement of the physical profile of the shaft to determine the mechanical runout. Once the mechanical profile has been determined, electrical runout can then be inferred – generally by simply subtracting the mechanical runout from the TIR measurement made with a proximity probe.

When assessing mechanical runout, accuracy is paramount. Special care must be taken due to the extremely small dimensions being measured. This requires a measuring instrument capable of resolving increments finer than 0.1mil (.0025 mm). While there are several choices for such instruments, some are more practical, accurate, and convenient than others.

• LVDTs (Linear Variable Differential Transformers)

LVDTs operate on the principle of a transformer with a movable core. As the core moves, the gain of the transformer changes and the displacement is inferred from that signal. Units are available with a resolution in the 0.01 mil (.0003 mm) range and are particularly well-suited for highly accurate mechanical runout determination.

• Dial indicators

While inexpensive, reliable, and found in most every machinist's tool box, mechanical dial indicators are generally limited to increments no finer than a tenth of a mil. Analog versions use a conventional needle-type indicator that can be very difficult to read with the required resolution, and for this reason are unsuitable for runout measurements. In addition, they do not allow for automated data acquisition.

Dial indicators with a digital display are also available, and are generally capable of providing the

necessary resolution. In addition, some of the more advanced versions feature an electrical output in addition to the display, making them suitable for automatic data acquisition.

• Form measuring equipment

These are specialized devices that evaluate components in terms of geometric dimensioning and tolerancing definitions. The machine typically holds the component vertically on a turntable and measures the form of the surface using a stylus. Output is the radial deviation from absolute roundness along with values describing the concentricity, eccentricity, and roundness as defined by Geometrical Dimensioning and Tolerancing (GD&T) standards. Unfortunately, such equipment is of only academic interest for most rotating machinery because it cannot handle components larger than 60 kg.

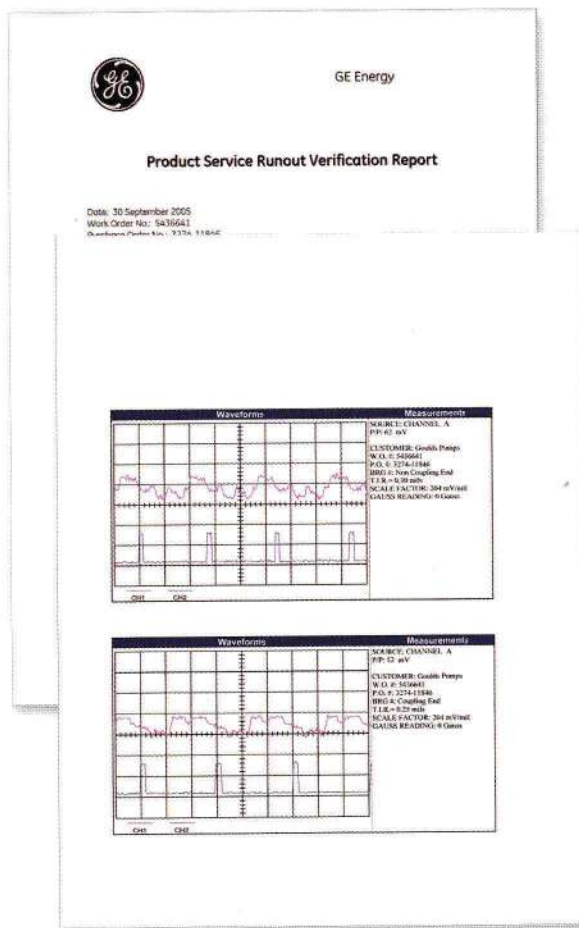
Based on the foregoing discussion, only two practical choices exist for measuring mechanical runout in most instances: LVDTs and electronic dial indicators.

Measuring Electrical Runout

Since electrical and mechanical runout are remedied in different ways, it is important to obtain separate profiles of the mechanical and electrical runout. Often, it is easiest to measure TIR and mechanical runout simultaneously. The electrical runout is then found by simply subtracting the mechanical runout from the TIR, as previously mentioned. Measurements should be made at suitably small intervals (typically every 10-20 degrees) to provide sufficient detail in the profiles.

While we have already discussed several practices that can help prevent electrical runout at the manufacturing stage, there are also methods (such as diamond burnishing and degaussing) that can be used to reduce electrical

runout once it is already present. These methods will be discussed later in this article. However, before attempting to reduce the amount of electrical runout, it is generally recommended that mechanical runout be addressed first, to try and bring the TIR within tolerances. This



Excerpt from a typical runout report for both coupling and non-coupling ends of a pump rotor. The top trace of each plot shows the runout waveform while the bottom trace shows the Keyphasor® pulse, indicating one complete shaft revolution between pulses.

serves two purposes. First, the processes of grinding and machining to further reduce mechanical runout can themselves introduce additional electrical runout. Thus, there is little point in proceeding to address excessive electrical runout until mechanical runout has been addressed. Second, because it is typically more difficult to address electrical runout, mitigation is generally only appropriate when mechanical runout reduction alone cannot bring the TIR to within the specified limits.

Sources of Error and Non-Repeatability

API 687 (Repair of Special Purpose Rotors) provides a very detailed description of how to measure runout. API specifications, in general, require that:

1. The shaft be supported in v-blocks;
2. The probe be perpendicular to one face of the v-block;
3. Runout be measured in terms of peak-to-peak probe output.

One of the primary reasons that v-blocks are recommended is that the runout measurement should be made in apparatus separate from that in which the machining was actually performed. For example, if a lathe has bearing wear that produces an elliptical shaft cross-section, the shaft will appear perfectly round as long as it is in that particular lathe. By moving the shaft to a separate measuring environment (i.e., v-blocks or a balancing machine), the error introduced by the lathe will not be masked.

However, while the use of v-blocks represents recognized good practice, it is not immune from its own sources of errors as detailed below.

• Failure to mount the probe perpendicular to one face of the v-block

This is a common error made in the field and results in incorrect mechanical runout readings. It affects only the mechanical runout measurement (not the electrical). The maximum mechanical runout error introduced is the sine of the probe's angular deviation from block face perpendicularity.

• Lobing Effects

As mentioned earlier, lobing is a common artifact of centerless grinding operations. When measuring the shaft profile in a lathe or other device where the shaft is rotated about its axial centerline, the user is measuring radial (rather than diametral) variations. As a result, there is no ambiguity in the profile measurement. In contrast, v-blocks cause the user to measure diametral variation, and can result in ambiguity regarding the shaft profile. This is easiest to visualize by way of examples, as shown in Figures 2 and 3.

Notice that the dial indicator in Figure 2 gives exactly the same output shape (dark blue line) for both shafts and that it reflects the change in diameter (not radius) as the shafts are rotated. The user may incorrectly conclude that the one-lobed shaft had a two-lobed profile, and efforts to correct this through grinding would only exacerbate the problem. In Figure 3, notice that the three-lobed shaft provides a dial indicator output suggesting perfect roundness, when, in fact, it has three lobes. Only by examining the motion of the center of the inscribed circle for all three shafts does the user obtain the true profile. This ambiguity can be removed by making the mechanical runout measurement with a fixture that rotates the shaft about its centerline (such as a balancing machine). As previously mentioned, it is not recommended that the measurement be made on the same lathe in which the shaft is being machined, as the runout measured becomes the combined effect of the shaft and the lathe bearings, and the two can offset one another.

Oil wedge – It is known that a film of oil builds up between two surfaces moving relative to each other. This oil film becomes part of the runout measurement and is unpredictable. A moving measurement may exhibit a dependency on shaft speed, even at slow roll. Thus, when documenting runout under slow roll conditions, it is important to record the actual shaft rotative speed.

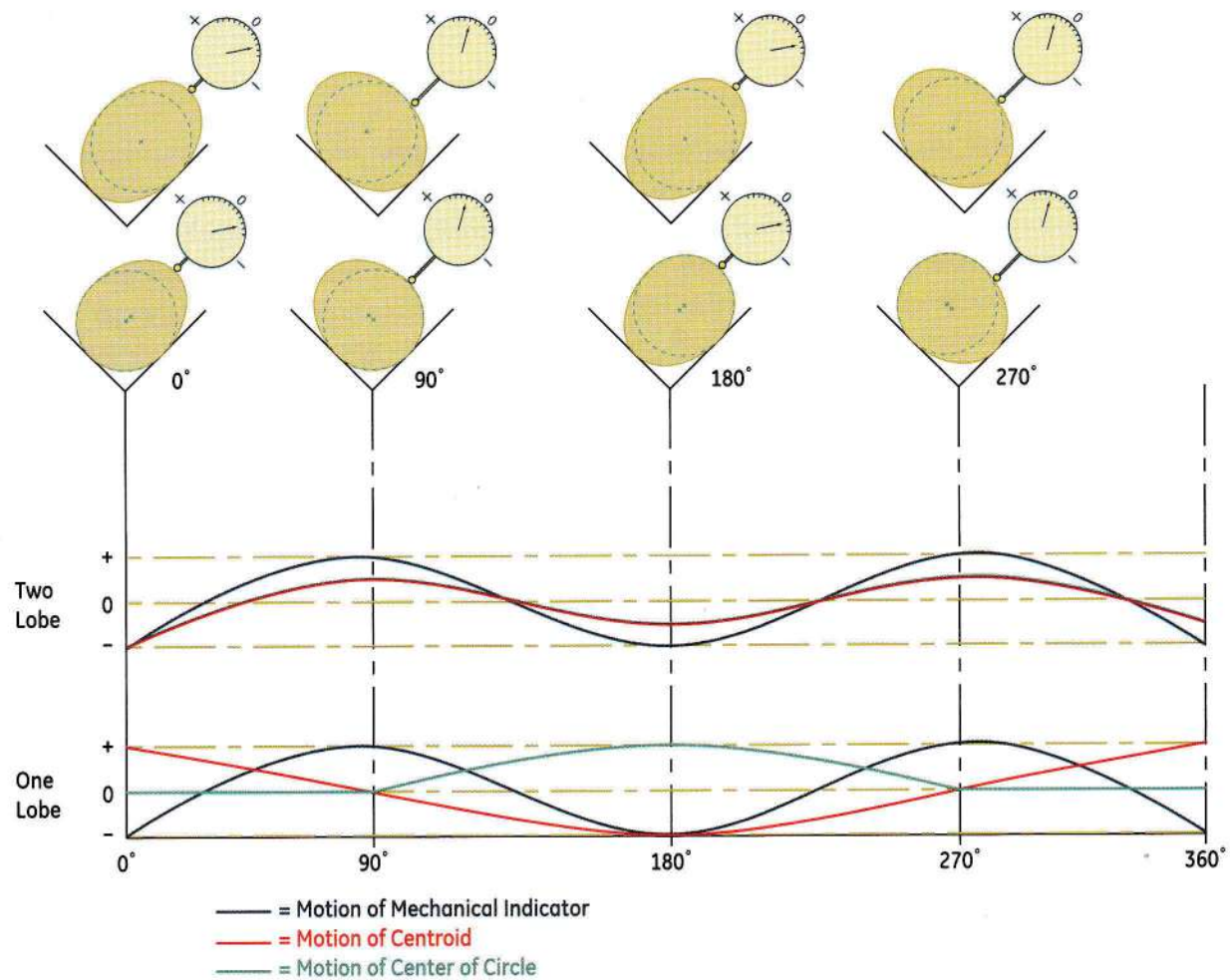


Figure 2 – When mounted in v-blocks and measured with a dial indicator, these one- and two-lobe shafts give identical dial indicator profiles. The only way to ascertain the true mechanical profile is to make the dial indicator measurements using apparatus that keeps the shaft fixed about its centerline – such as a lathe. This allows radial, rather than diametral, variation to be observed.

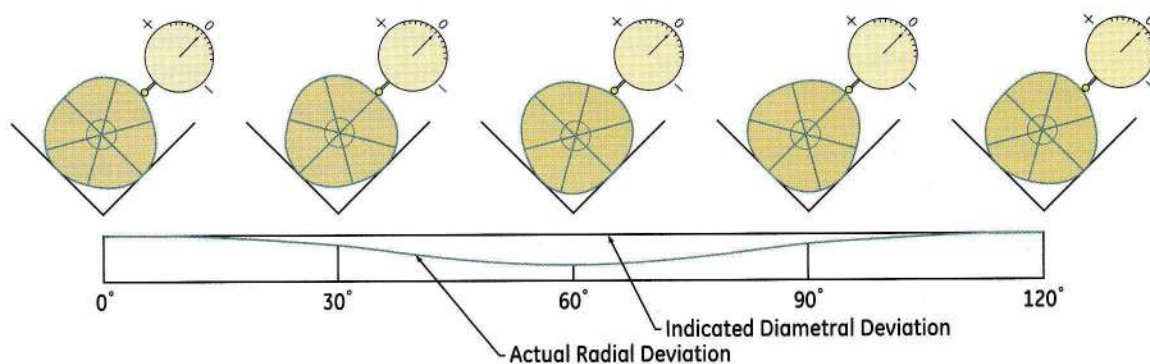


Figure 3 – This 3-lobed shaft appears to be perfectly round when mounted in v-blocks and measured with a dial indicator.

WHEN ASSESSING MECHANICAL RUNOUT,

ACCURACY IS PARAMOUNT.

Stick slip – V-block measurements will sometimes use an apparatus (such as a drive belt) that slowly rotates the shaft. However, manual barring of the shaft is most common. While API specifications recommend rotation intervals of no more than 20 degrees, this is a relatively large gap between data points. As the rotor is moved, it may not settle into position repeatably, leading to significant error. To help counteract this “stick slip” effect, smaller measurement intervals (10 degrees or less) are recommended.

Bow/sag – If a shaft has a bow or sag from gravity (and all shafts exhibit some level of this), it is possible that this will show up as runout as the shaft flexes during rotation. Anisotropic stiffness (unequal with respect to direction) will definitely cause irregularity in the runout reading due to rotor sag. To minimize this effect, make the runout measurements as close as possible to the shaft supports (e.g., v-blocks).

Inconsistent Transducer Models – When measuring TIR, it is not necessary to use the same probe in the shop as the installed probes in the field, as this is rarely practical. However, it is strongly recommended that the same probe *series* be used to eliminate possible sources of inconsistencies. For example, if the machine will be permanently monitored with Bently Nevada 3300 XL 8mm proximity probes, it is advisable to use this type of transducer system for the bench runout measurements as well. While the differences between transducer series are generally small, runout measurements are typically trying to resolve dimensions of 0.25 mils or less. As such, even the smallest sources of variation can affect the results.

Methods of Mitigating Electrical Runout

The old adage “an ounce of prevention is worth a pound of cure” is particularly true for electrical runout. In the section “Sources of Electrical Runout,” we noted a variety of things that can lead to electrical runout and offered advice on how to carefully choose and handle materials to minimize the potential for electrical runout. However, if excessive levels of electrical runout exist, there are steps that can be taken to reduce them.

Degaussing (Demagnetizing)

One method of checking residual magnetic field strength is by using a small, hand-held field indicator, available in digital and analog versions from manufacturers such as Magnaflux®. Even a relatively small amount of localized residual magnetism can contribute to runout. For example, a localized concentration of 5 gauss on a rotating shaft can give electrical runout on the order of 0.5 mil. Therefore, it is always good practice to check the shaft with a field indicator and, if required, degauss in the area of the probe tracks.

A degausser emits an AC pulse of decreasing strength. The magnetic field generated “scrambles” the domains in the material to reduce the residual magnetism. While special degaussing apparatus is available, a very common field practice is to use an arc welder set to AC with the cables shorted together. The cables are waved over the area to be degaussed, or sometimes wrapped around the shaft. The current in the cables sets up a large enough magnetic field to effectively degauss the shaft.



A diamond-tipped burnishing tool. The tool is mounted in a lathe and can provide surface finishes of 10 microinches or less. When used by a skilled practitioner, diamond-tip burnishing can be effective in reducing electrical runout because it alters the shaft's crystal structure.

Probe Gap

A simple first attempt at reducing electrical runout is to gap the probes closer to the shaft. Sometimes this can change the runout measurement. However, be certain that the probes are not gapped so close that they take the probes outside their linear region or allow the probes to contact the shaft during periods of high vibration.

Burnishing

Burnishing is a technique of smoothing the surface of the shaft using a rounded diamond tip mounted on a lathe. The burnisher tip is pushed against the shaft surface by a spring loaded tool holder. This process mechanically alters the crystal structure on the surface of the shaft by plastic deformation, allowing surface finishes of less than 10 microinches to be realized. While burnishing can be an effective method of reducing electrical runout, it is more of an art than a science. Unless applied by a skilled practitioner, burnishing can actually worsen electrical runout. Further, if some burnishing is good, more is not necessarily better. Once burnishing has minimized the electrical runout, additional burnishing may increase rather than decrease the runout. For these reasons, we have deliberately chosen not to include step-by-step burnishing instructions in this article. Instead, customers

are strongly encouraged to enlist the assistance of a qualified GE services professional when burnishing is required. In addition to performing the burnishing work, these individuals can provide the necessary hands-on training for those customers that prefer in-house competencies in the use of burnishing tools.

Alternate probe track material

In some instances, electrical runout can prove quite intractable. In such instances, the most expedient solution is generally to use an alternate target material for the probe to observe. The two most common methods for this are collars and coatings.

• Collars

Collars can be very effective, provided they are attached to the shaft in such a way that they cannot come loose or induce additional loads or stresses on the machine. Additionally, the collar must be ground after it is shrunk onto the shaft to ensure that it is suitably concentric. However, some shaft geometries cannot accommodate a collar. In other situations, the shaft geometry may allow for a collar, but significant thermal gradients due to differential expansion problems may make use of a collar unwise.

• Coatings

Depositing a layer of less runout-prone material onto a shaft can be employed successfully, and there are several technologies for this. The idea is similar to that of plating (already discussed) and many of the same considerations apply. Primary concerns are to choose a material that is non-ferrous and applies with sufficient density that inclusions do not generate a runout signal of their own. The material must also be applied in a thick enough layer to prevent the probe from seeing through to the substrate.

Obviously, both approaches require a proximity probe system calibrated to the target material, not the shaft material.

A Word About Compensation

When performing machinery diagnostics, a common practice is to subtract a known runout signal from the overall vibration waveform to obtain a "runout-free" waveform. This is known as compensation and is a way of dealing with both mechanical and electrical runout. Many diagnostic products (such as the ADRE® System and System 1® software) allow such compensation. In addition to waveform compensation for unfiltered plots such as timebases and orbits, the signal can also be filtered to a specific frequency, such as shaft rotative speed (1X). This allows it to be characterized as a vector and used to compensate filtered plots (such as Bodé and Polar – see Figures 4 and 5).

Occasionally, users will request that we provide compensation features in our permanent monitoring hardware. Both vector and waveform compensation are valuable features when performing machinery diagnostics, and the runout signal can generally be validated and updated as needed as part of the diagnostic process. This is not the case for permanent monitoring and we strongly advise against the use of compensation for machinery protection applications. Runout signals can change over time due to factors such as surface scratches incurred during operation or maintenance, and/or changes in the amount and distribution of shaft magnetism. When compensation is embedded in a permanent monitor, the runout profile stored in the monitor

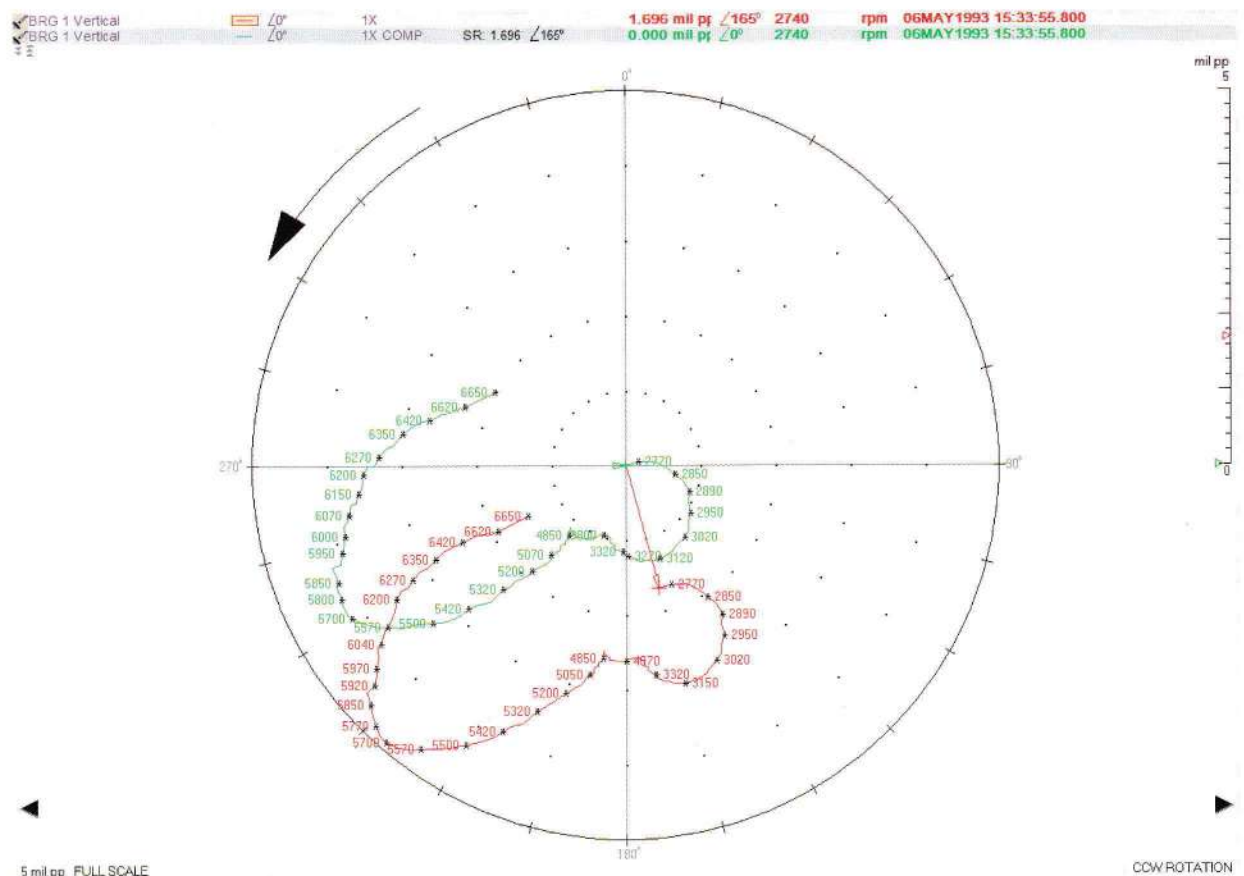


Figure 4 – ADRE® Sxp software is one example of a diagnostic system that provides runout compensation features as shown by the compensated (green) and uncompensated (red) data in this polar plot. The red arrow denotes the 1X runout vector. For a polar plot, compensation has the effect of shifting the data to the origin at slow-roll speeds.

remains fixed even though the actual runout may be changing over time.

The nature of combining waveforms and vectors is that they reinforce in some places and counteract in others – unlike simple scalar addition. Figure 5 illustrates this concept, showing how the runout signal increases the observed vibration signal in some places (i.e., below 6200 rpm) and decreases it in others (i.e., above 6200 rpm).

In this case, the vibration is changing while the runout remains fixed. However, the same effect can occur when the runout is changing, regardless of whether the vibration levels are stable or changing. Changes in runout may make the vibration look worse than it actually is,

or they may mask legitimate high vibration problems, phase changes, or other conditions indicative of an emerging machinery malfunction.

Back when Bently Nevada™ monitoring hardware utilized analog meter movements, users would sometimes want to “compensate” for runout by using the offset adjustment potentiometer in the meter. For example, if the peak-to-peak amplitude of the runout signal was 0.5 mils, they reasoned that they could simply offset their meter by 0.5 mils. Thus, a meter that would normally indicate 3.2 mils of vibration would indicate only 2.7 mils. This approach was particularly faulty because it not only failed to recognize that runout can change over time, but

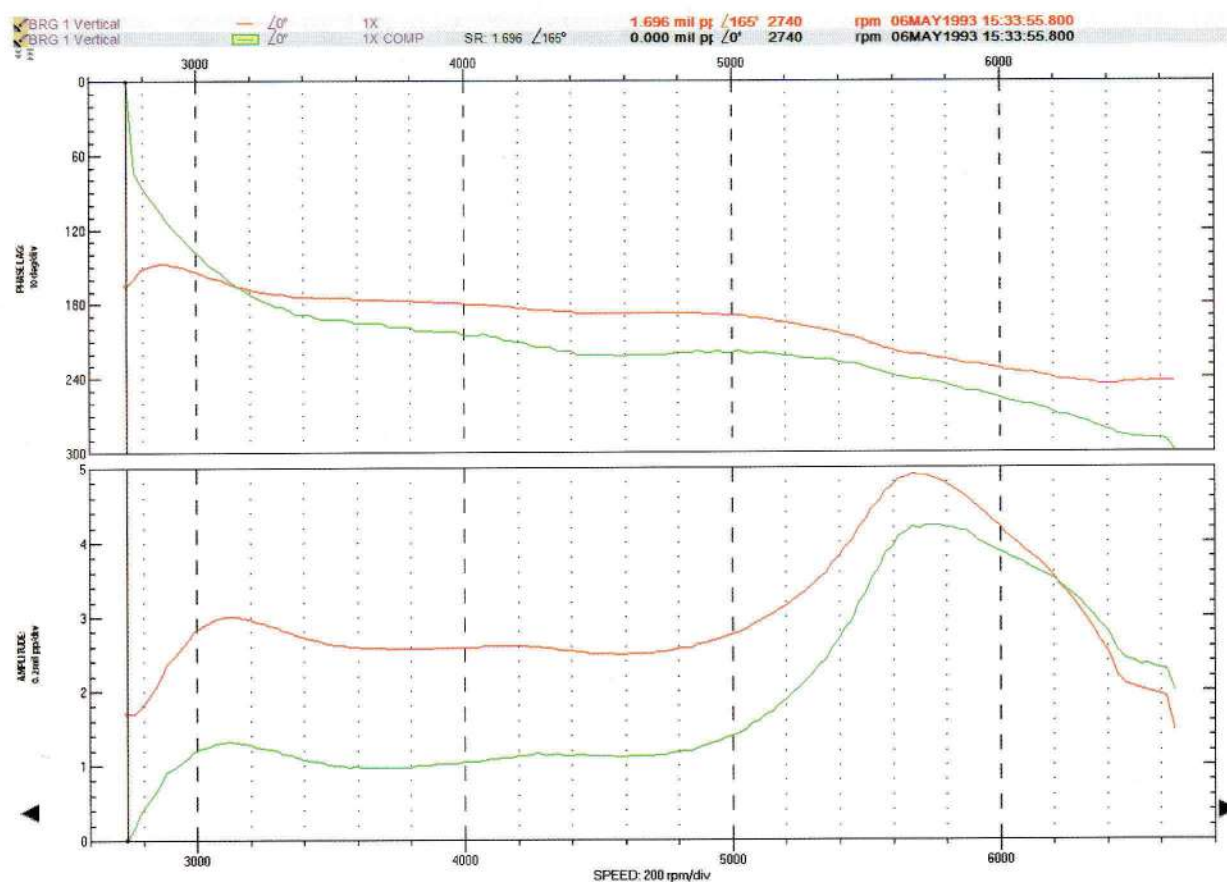


Figure 5 – Bodé plot of same data as in Figure 4. Notice how the compensated data (green) has lower amplitude than uncompensated data (red) below 6200 rpm, but this is reversed for speeds above 6200 rpm. The complex nature in which vectors and waveforms combine can cause runout to either increase or decrease the actual vibration amplitude.

Slow Roll Runout as a Diagnostic Tool

As pointed out in this article, runout can change, and for this reason, embedded compensation in a permanent monitoring system is not recommended. However, runout can vary for more reasons than just shaft scratches or changes in shaft magnetism. One of the most serious malfunctions that can result in a runout change is a shaft crack. While this is not the only symptom of a crack, any time the slow roll (typically less than 400 rpm) runout amplitude/phase vectors change, it is imperative to understand why.

Our first rule of shaft cracks states that, "If a shaft is cracked, it is almost certainly bowed." This bow can change the 1X slow roll runout vectors once crack propagation takes place. Thus, if the shaft is bowed, it may simply be gravity sag, or it may be more serious. The 2X slow roll runout vector should also be checked. Cracks can cause stiffness asymmetry if they propagate in an uneven pattern, creating a characteristic twice-per-revolution flexing. Certain rotor designs are inherently asymmetric – such as 2-pole generator rotors, – where "normal" shaft asymmetry will yield a noticeable 2X component, but its amplitude and phase should not change over time.

The moral of this story? Always remember to treat runout data as a valuable source of diagnostic information – not merely "noise" that interferes with the true vibration.

You can read more about the topic of shaft crack in the January 1986 issue of ORBIT.

that runout is a complex waveform and does not follow the rules of scalar subtraction.

The inherent problems in using embedded compensation in machinery protection systems was addressed a number of years ago in American Petroleum Institute Standard 670. It specifically prohibits the use of compensation in permanent monitoring systems. Consistent with API 670, it has long been our practice to provide compensation in systems used for diagnostic purposes, but not machinery protection purposes.

Summary

As we have shown, many factors can influence the amount of runout present in a shaft. The best approach is to prevent runout – rather than mitigate it after the fact – through appropriate diligence at all stages of the manufacturing process. However, mitigation will still sometimes be necessary and this article has discussed several methods that can be employed with good success, ranging from degaussing and burnishing to the use of alternate materials for the probe tracks. In all situations, runout can be effectively managed and should not preclude users from using proximity probes on machinery with fluid-film bearings, as these transducers afford the most sensitive and reliable machinery condition measurements available.

For those experiencing runout-related problems or desiring to prevent such problems from occurring in the first place, an excellent approach is to enlist the service of GE Energy's field professionals. They can develop a runout mitigation plan specific to your operations as well as provide the necessary training for your personnel. 

Errata

In the Gas Turbines issue of ORBIT (Vol. 25 No. 1) published earlier this year, an astute reader found a mistake in our article on Overspeed Detection Systems. On page 18, the article incorrectly stated that "a 50% increase in speed results in a 225% increase in force." Mr. Kashif Ali, an Operations Engineer with Kot Addu Power Company (KAPCO) in Pakistan, correctly noted that a 50% increase in speed actually results in a 125% increase in force (which is 2.25 times the original force). Our thanks to Mr. Ali for bringing this to our attention. ORBIT apologizes for the error.

Knowledge³TM

A Platform for Process Modeling, Optimization, and Control

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Introduction

GE Energy has a long history and deep expertise in both condition monitoring and machinery/process control. As tools for analyzing asset condition, such as mechanical and thermodynamic performance, have evolved and proven their value, it was natural for customers and GE to look for ways to expand existing technology to new applications. Some of these tools, such as the Closed Loop Optimization and Control (CLOC™) System discussed in the last issue of ORBIT, represent the marriage of modeling and condition monitoring (in this case, thermodynamic performance) with closed-loop control, allowing an entirely new level of optimization effectiveness. Other technologies, such as the RuleDesk™ utility in System 1®

software, focus on allowing users to embed rules-based diagnostics to automate labor-intensive processes (in this case, tedious review of condition monitoring data).

Here, we are pleased to introduce ORBIT readers to an entirely new platform that blends these capabilities, while adding many others, and extends well beyond traditional asset management applications to the broader scope of generalized process modeling, optimization, and control. We call this platform Knowledge³™ (Kn³), because it blends three distinct knowledge-capturing capabilities into a single tool: modeling, optimization, and control.

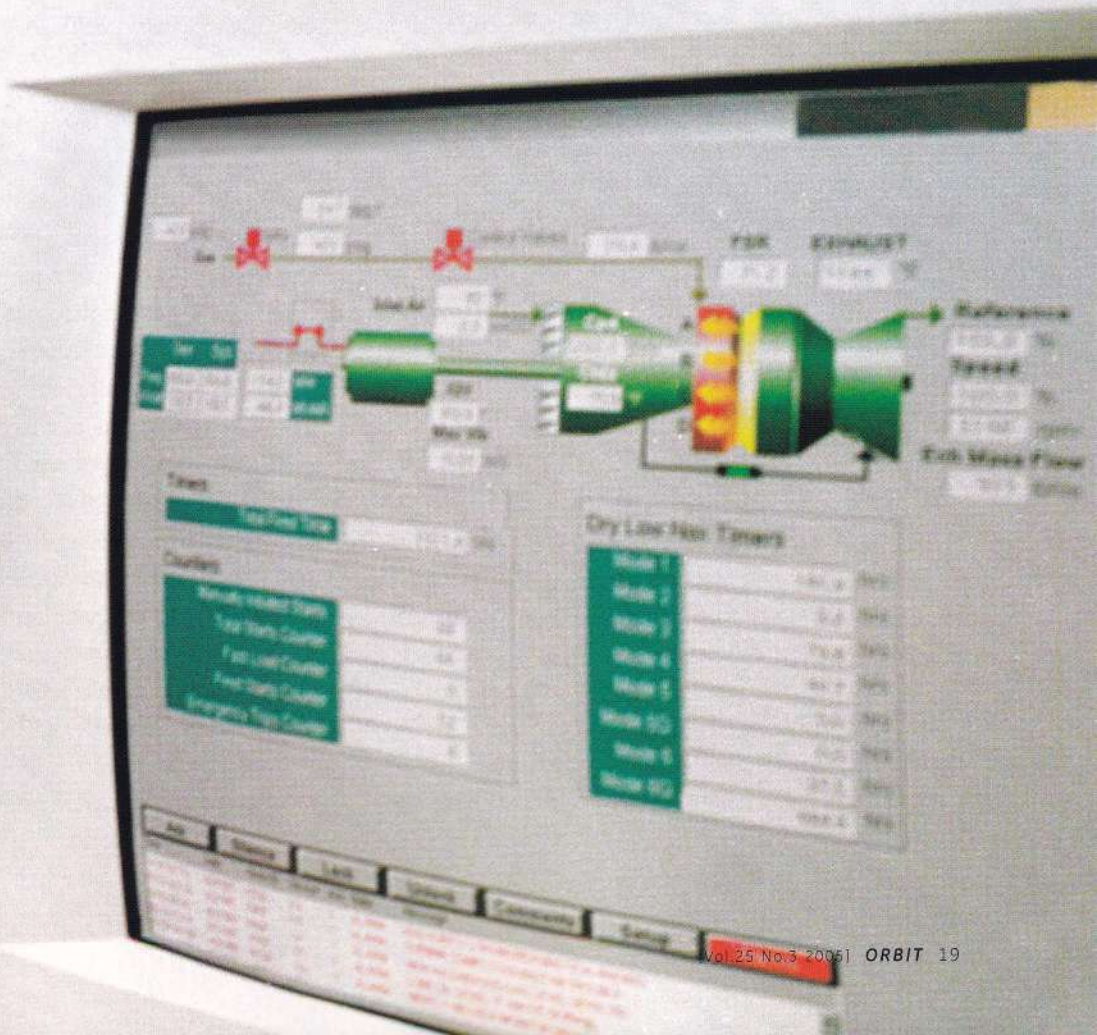
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A New Platform for New Applications

Kn³ embeds portions of the proven technologies used in several of our other purpose-built tools. For example, the multi-variable control module used in our CLOC™ System and the rule-building environment of System 1® software can both be found in the Kn³ platform. Kn³ also allows users to consider a much broader range of optimization, modeling, and control opportunities that complement the optimization tools already available from GE. As a

result, Kn³ has emerged as an extremely powerful, yet generically applicable tool, able to address virtually any industrial process or application. For example, a Virginia power generation facility is presently using Kn³ to optimize a coal boiler. There are numerous other applications, and later in this article, several of these potential applications will be discussed. First, however, an overview of Kn³'s capabilities is in order.

Kn³ Process Modeling



Process engineers have long understood that "first principles" models are not always practical for particularly complex processes or those with extreme sensitivity to initial conditions. This makes modeling and controlling such processes a significant challenge, particularly when trying to optimize.

To deal with highly complex processes that don't easily lend themselves to first-principles modeling, the process engineering community has increasingly harnessed neural network technology. There are proponents for both sides – some who adamantly oppose anything except first principles, and others who believe the heuristic approach made practical by high-speed computers and neural nets renders a first-principles approach obsolete. In truth, however, both approaches have merit. Tools that can blend the best of both approaches generally demonstrate the broadest applicability and effectiveness.

Recognizing this, the Kn³ platform allows users to implement a purely rules-based approach, a purely neural-net approach, or any combination of the two.

1. Rules

Detailed, easily configurable rules can be written on any combination of data entering or leaving the Kn³ platform.

Rules include mathematical and logical operations, allowing the user to combine data for better and more detailed results. Rules can also be used to visually alert users that an improper operating condition has occurred (or is developing), allowing proactive intervention.

2. Neural Nets

The Kn³ platform allows the development of predictive models, using neural networks, for key outcomes resulting from a process. Neural networks computationally mimic the nervous system of the human body. The system uses inputs (stimuli) to predict outputs (responses) based on the patterns "learned" by the system. Training the system to develop a corresponding model is done by using historical and/or measured data. The goal of the model is to properly characterize outputs given inputs. Here, inputs consist of data that are known to impact the process. The success of neural networks in a wide variety of applications – even those with complex behavior such as weather forecasting – is outstanding. Accuracy is generally greater than 95% and often higher than 99%. In addition, Kn³ is designed to automatically retrain neural networks based on data acquired on-line, when their predictive performance has become inaccurate. In this way, the models never grow static and accuracy is maintained even as conditions change.

Kn² Optimization



The Kn³ platform provides sophisticated, multi-objective optimization, allowing several different goals to be addressed simultaneously. The optimization uses the modeling described above to provide predicted results for a specified set of inputs. The optimization iteratively updates inputs, progressively driving the calculation efficiently and accurately towards the best set. The determination of “best inputs” is based on those that achieve the goals in the optimal way while observing all constraints. For example, inputs for the model would generally be all the *possible* setpoints for the underlying

basic process control system. Outputs would be the best combination of setpoints that influence the process to result in optimal efficiency, emissions, product quality, throughput, or whatever else was the goal of your optimization.

The optimization technology used for this purpose is Genetic Algorithms (GAs). GAs are renowned for consistently finding the true optimal solution and use a process that mimics those found in nature. It is a mature technology that has been used effectively in numerous processes.

Kn³ Control



When coupled with GE's MVC® (Multi-Variable Control) system, users can effectively “close the loop” with the optimized setpoints found by Kn³. MVC implements the optimal setpoints calculated by Kn³ by sending them to the underlying regulatory control system. It does this in

a manner that ensures there are no abrupt process changes or upsets while observing all required control constraints. MVC is a mature, proven technology that GE Energy has applied in several other products including the CLOC™ system for combined-cycle plants.

Data Management Tools

Kn³ is designed to address all relevant data and information about the process you are modeling, optimizing, and/or controlling. The platform has a powerful data management engine that allows it to acquire data from a variety of sources, validate it, and write custom rules combining data and results in useful and powerful ways. Unlike other environments in which application flexibility

comes at the price of a complex and unwieldy platform, Kn³ is very easy to use and configure. It incorporates the configuration engine and highly intuitive RuleDesk™ technology of System 1® software, allowing graphical development of algorithms rather than requiring fluency in a complex programming language.

User Interface

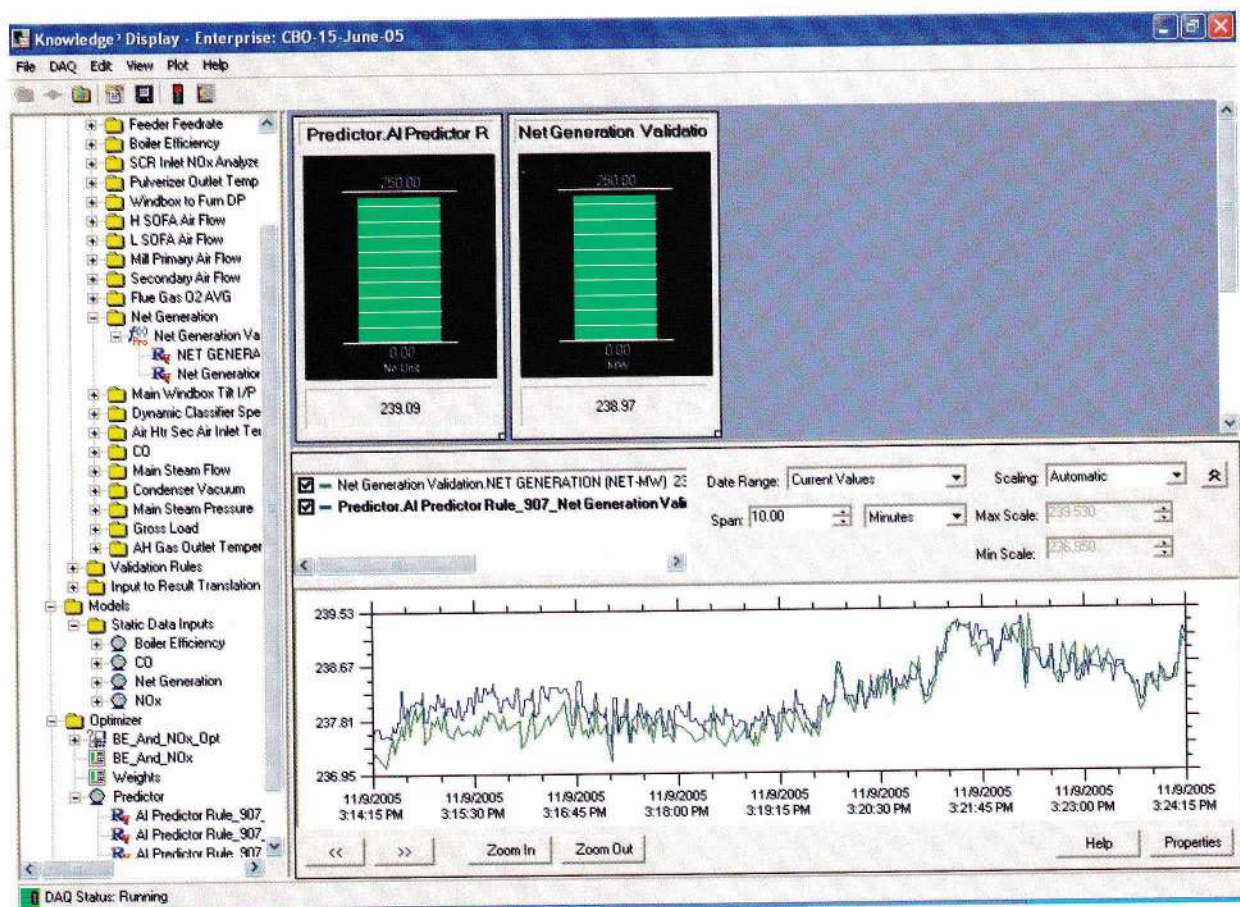
Kn³'s Graphical User Interface (GUI) allows the product to be used off-line or on-line, permitting users to test and validate results, build models, and perform diagnostics in both real time and archived environments. The GUI is also highly configurable, allowing users to customize the look and feel of individual screens according to their needs.

Principal functionality within the GUI includes:

- display of data, rules, model configurations, and operating statistics;
- display of data used in the models including current values and predicted values;

- display of optimization results including current and optimal values;
- visual alarms to alert users of an operating condition requiring action;
- and, historical trending of all relevant data.

When applied online, Kn³ incorporates standard client-server architecture. The GUI software (client) can be loaded on any machine on the network, accessing data from one or more servers. Off-line, the entire software program can fit on a desktop or laptop computer, providing a fully self-contained tool that can travel with you.

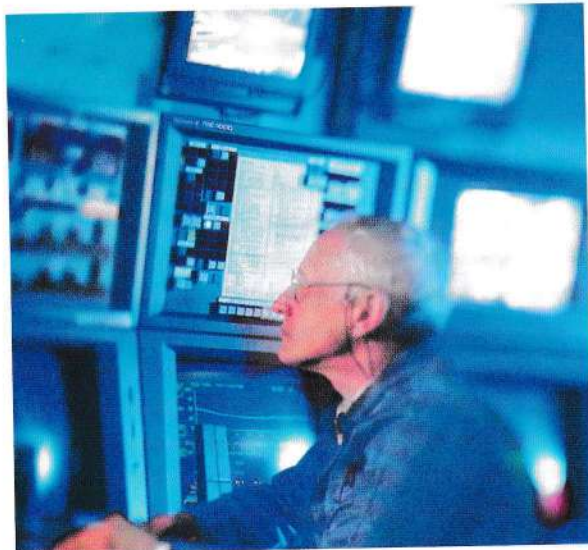
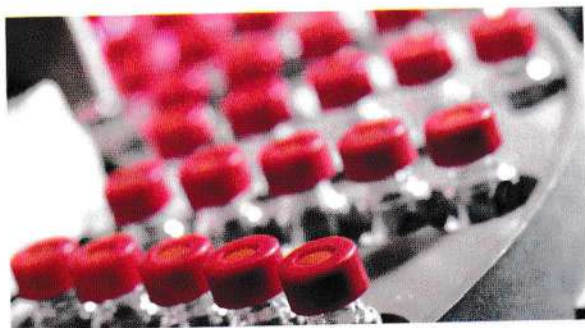


Kn³'s user interface is easily customizable, designed to address the diverse processes for which modeling, optimization, and control is required.

Potential Applications and Benefits

The possible applications of Kn³ are limited only by the user's imagination and the availability of good data that

accurately characterizes the process. Here are some examples:



• Energy Optimization

Kn³ can be applied to a variety of energy-related processes such as power and steam production, pipeline optimization, and grid management. One example, is coal boiler optimization where the goals are to improve emissions, efficiency, and/or availability. For coal boilers, Kn³ can range from simply a scenario tool (modeling), to open-loop optimization (add optimization), to closed-loop optimization (add MVC). The product is currently in use on a 220-MW coal boiler in Virginia to reduce NO_x emissions while simultaneously improving boiler efficiency.

• Improved Production Quality

Kn³ can be applied to processes as diverse as steel and pharmaceuticals. The goals in these types of applications are to improve the quality and quantities produced, while reducing costs – without violating process constraints.

• Diagnosis

Kn³ is particularly useful for diagnosing problems or identifying anomalies in highly complex data that does not lend itself to rules-based analysis. Many times, conditions can change so slowly or give such subtle warning signs that conventional rules will simply not flag anything as abnormal. A particularly powerful capability of neural nets is their ability to spot anomalies. Knowing there is a problem – even when root cause has yet to be determined – allows users to be far more proactive than waiting for symptoms to progress to more “obvious” levels that can be detected by a rule. As one customer explained, “waiting until you know the solution to tell me there is a problem may be too late.” Combining both rules-based and neural net capabilities has particularly powerful applications in the condition monitoring realm.

• **Pattern Recognition**

With its neural net technology, Kn³ is an excellent tool for pattern recognition. Neural nets can be applied successfully to several processes related to pattern recognition, whether it is identifying a sequence of events that may have previously gone unnoticed yet always precedes a particular process upset, thermography images, or applications as diverse as MRI scans in health care, weapons identification in luggage for airport security, and face recognition for law enforcement. In all these examples, the more accurately and efficiently patterns can be recognized, the better and less costly the process. Kn³'s added advantages of being able to manage data and apply rules makes it uniquely powerful and applicable in this arena.



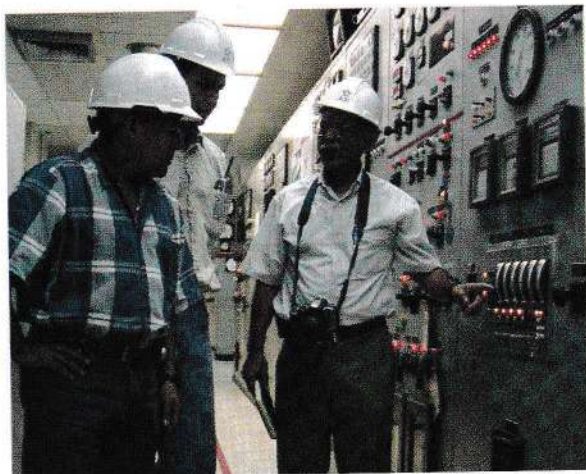
Summary

Kn³ expands the proven rules-based analysis technology used in GE Energy's condition monitoring applications by adding several state-of-the-art technologies and allowing users to model, optimize, or control virtually any process. Because the tool can

deliver any of these functions individually or in combination, it is uniquely flexible and powerful, equally relevant to process design engineers, process control engineers, and plant diagnostic engineers. 

ANNOUNCEMENT

Who Has the Oldest Monitor?



Since this issue commemorates the 50th birthday of Bently Nevada™ Asset Condition Monitoring, we thought it might be fun to ask our readers to submit a photo of the oldest monitoring system still in use. Guillermo Perez, one of our long-time sales engineers for Latin America, recently sent us this photo (he's the one with the camera) showing a 5000 Series Monitoring System still in use. The monitor dates to about 1970 and is located in the control room for the Panama Canal's Miraflores Locks. Do you have a Bently Nevada monitoring product that is this old or older? We'd love to hear about it. Just drop a line to the ORBIT Editor using the mailing address on page 2, or send an e-mail to orbit@ge.com. 

3300 XL Ceramic Capped Probe

Fritz Schweigert

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For many years, Bently Nevada™ proximity probes have been used to address machinery vibration and position measurements in harsh environments. While our standard probe construction is suitable for the pressures, temperatures, and chemical environments encountered in most applications, there are times when particularly high pressures or extreme pH environments dictate special probe materials. One example of such an environment is found in machinery handling anhydrous ammonia.

For such applications, we are pleased to offer an extremely robust proximity probe using an alumina cap protecting the transducer's tip and a 304 stainless steel case. These materials have demonstrated superior performance in such environments. The ceramic tip is helium leak tested to ensure a hermetic seal – keeping the transducer's inner workings safely protected from the corrosive environments in which the probe is immersed.

Two configurations are available. The first seals only the ceramic-to-metal interface on the front of the probe. It is suitable for applications where the probe is threaded through a bearing housing or other physical interface separating the harsh environment from the outside world. The second configuration seals both the front and back of the probe (where the cable exits the probe case), and is appropriate when the entire transducer and some or all of its integral cable will be subject to an environment where corrosive materials can enter the probe at either the front or rear. For ease of installation with the completely sealed version, the tubing protecting the transducer's integral cable can be removed and slid out of the way when installing or gapping the probe, and then tightened to provide a complete seal.

The new 3300 XL Ceramic Capped Probe is specifically designed for addressing machinery in environments such as anhydrous ammonia.



The transducer provides a 1.52 mm (60 mil) linear range and electrical performance identical to our 3300 5mm transducer. The probe is compatible with standard 3300 XL Proximitor® sensors and extension cables. However, because the ceramic cap results in a shift in the probe's linear range, special care needs to be exercised when gapping the probe to ensure that the probe tip does not contact the shaft. In some cases, a special modification to your monitor may be required to accommodate the differing OK limits of a ceramic capped probe when compared to those of a standard 3300 5mm probe.

You can learn more about this new probe by consulting your nearest sales professional, or by accessing the product's datasheet on www.gepower.com/o&c/bently. For rapid navigation directly to the datasheet, simply enter the datasheet number (172932) in our site's search engine. 



Jeff Schnitzer

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Looking Forward

As the new General Manager for Bently Nevada™ products, I'd like to take this opportunity to introduce myself and talk briefly about our first 50 years and what I think the future holds.

My introduction to "asset management" was during four years in the US Air Force as a crew chief. It was my job to get the asset mechanically ready for its next mission. In this case, the assets were C-141 aircraft, but the principles are essentially the same as with plant assets – availability and reliability are paramount. My time in the Air Force was followed by a Mechanical Engineering degree from SUNY at Buffalo, and then joining GE. One of my first GE jobs was as a Manufacturing Engineer with responsibility for launching a preventive maintenance program, building on my asset management experience from the Air Force. I have also spent a lot of time in operations and quality roles at GE. Most recently, I was general manager for GE's Reuter Stokes product line, providing harsh environment measurement solutions for Nuclear Boiling Water reactors and down-hole O&G exploration and production.

My background really sums up to this: understanding the critical parameters for getting a "process" to work and being able to measure and control it. This is in my DNA and is very much about who I am and what I am passionate about.

It has been a little over 90 days since I started in my new role and I have spent a lot of time honing my understanding of the "process" that has made the Bently Nevada product line so successful in the past. Here is what I have found: leading technology, excellent quality, subject matter expertise, strong emphasis on customer support and service, and training to help customers help themselves. Even though the technology we design and build is often quite complex, business success is as much about the fundamentals as about the technology – treating customers the way we would want to be treated, making sure we understand and

meet or even exceed their needs consistently. If the first 50 years were about anything, they were about doing these things with consistent excellence.

As I look forward to where my focus will be in leading the Bently Nevada product line into 2006 and beyond, I've identified 3 main areas. First, to make absolutely certain that I keep the business focused on what has made it so valuable to you, our customers. In other words, the fundamentals. Second, to keep investing in technology. I want to make certain that we continue to bring to bear everything we've learned during the first 50 years to the design of tomorrow's products so that the Bently Nevada name continues to be synonymous with "best quality, best functionality, best reliability, best value." Finally, I want to make sure that our product portfolio continues to expand so that customers can turn to us for the other essential equipment in their plants rather than just the critical turbomachinery for which we are best known. Reducing maintenance costs and improving availability on all plant assets are tremendous benefits that we provide for our customers through our product and service offerings. It's obvious to me that the solutions being used by customers in our two primary industries – power generation and hydrocarbon processing – offer these same benefits in other industries, such as pulp & paper, cement, pharmaceuticals, and many other discrete and continuous manufacturing processes. We already have some success in these places, but I want to ensure we are identifying new customers in such industries and delivering value to them, even as we continue to take excellent care of existing customers in our "core" industries.

In closing, you'll hear from me periodically in this column, and I'm sure I'll meet many of you both as I travel and as you visit us here in Minden. You can rest assured that I am focused on nurturing the things that made the Bently Nevada product line so successful during its first 50 years, helping ensure the next 50 are even more successful for you and for us. 



Proactive Rotating Equipment Asset Management at Mirant Philippines' Pagbilao Power Station

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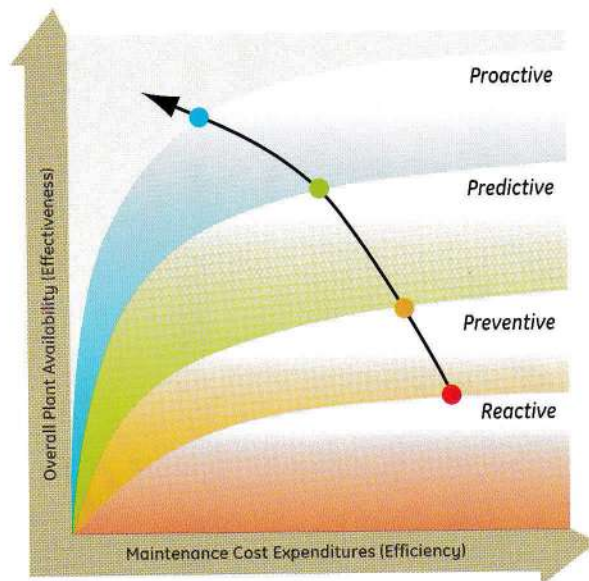
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Introduction

In the late 1980s, the Philippine government requested private sector assistance to meet the country's growing electricity demands. Mirant was the first company to respond and has consequently emerged as the largest foreign investor in the country. Today, Mirant has an ownership interest in nine fossil-fueled power plants in the Philippines. The Pagbilao (735MW) and Sual (1218MW) plants are coal-fired and enjoy distinction as the largest and most cost-efficient power generation facilities in the country, providing high-quality, reliable electricity to the Luzon power grid and serving the energy needs of more than 40 million Filipinos.

Both plants have invested in System 1® software for managing their rotating equipment assets. This article describes how the Performance Engineering team at the Pagbilao plant justified the purchase of these systems, the scheme they employ to categorize assets into critical, essential, and balance-of-plant classifications, and the relevant technology chosen by Mirant to address the condition monitoring and machinery protection needs of each category. The article concludes with two case histories demonstrating how the installed systems have been used to solve actual machinery problems.

Figure 1 – Maintenance Strategies.



Maintenance Strategy	Top Quartile	Lower Quartile
Proactive	>20%	0%
Predictive	>45%	~12%
Preventive	>25%	~31%
Reactive	>10%	~55%

Sources: Society of Maintenance & Reliability Professionals Survey; The Business Case for Reliability, Robert DiStefano, John Schultz.

Why Proactive Asset Management?

Maintenance is typically the second largest cost in any power station. Increasingly, power companies are looking at ways to reduce their maintenance spend and therefore improve overall plant profitability. Simply cutting the amount of maintenance may have a short-term benefit in terms of reduced expenditure, but it is not a sustainable practice and typically leads to greater expenditure in the medium term. When expressed as efficiency (how much is spent on maintenance) versus effectiveness (the overall availability of the plant), the goal is to improve efficiency while simultaneously increasing overall plant availability.

The key to achieving these improvements is an on-demand ability to generate "actionable information" regarding asset condition. In other words, information

that plant personnel can act on rather than merely large volumes of condition monitoring data that requires further interpretation. It is this "actionable information" that enables proactive asset management.

Figure 1 illustrates the linkage between efficiency, effectiveness, and the four main maintenance strategies. As one moves up the chart from reactive to proactive, the maintenance spend required to achieve a given level of plant availability decreases. Thus, proper balance of these maintenance strategies can indeed achieve the simultaneous goals of greater maintenance efficiency and greater plant availability. The embedded table in Figure 1 also illustrates another important point: top quartile companies rely on predictive or proactive strategies for at least 65% of their overall maintenance practices.

Technology, Methodology & People

Achieving the simultaneous goals of increased maintenance efficiency and improved plant availability requires investment in three specific areas: people, methodology, and technology.

Technology is typically the easiest part because there is an abundance of very good systems available to manage plant assets. The methodology part is also relatively straightforward. Much headway has been made in recent years identifying and documenting the relative merits of various maintenance strategies and methodologies. For end users, it simply becomes a matter of selecting a methodology and a trusted vendor with the technology they seek. However, while these are necessary for enabling the shift from the current situation to the desired situation in a plant, they are not sufficient.

Without properly addressing the people who will actually use the technology and employ the methodologies, the plant will remain mired in its present state. Indeed, things may actually get worse because money will be spent without any corresponding benefit.

At Pagbilao, the Performance Engineering team was an integral part of the overall improvement strategy. This helped ensure clear ownership and the ultimate success of the initiative.

Asset Criticality Assessment

Prior to selecting the technology at Pagbilao, the Technical Services Performance Engineering team conducted a criticality assessment of the plant's rotating equipment assets and came up with three specific categories, as shown in Table 1.

Table 1 -

ASSET CRITICALITY CATEGORIES AND CORRESPONDING MONITORING SYSTEMS

Classification	Defining Attributes	Representative Asset Types	Appropriate Instrumentation	Typical Platform
Critical	Impact of failure or unavailability directly affects plant production.	- Main turbine generators - Boiler feed pumps	- Online, continuous machinery protection - Online, continuous condition monitoring	Bently Nevada 3500 Series with internal or external communications processor
Essential	Impact of failure or unavailability does not directly affect plant production, but risk to plant availability increases.	Condensate pumps	Online, periodic condition monitoring	Bently Nevada Trendmaster® Pro
Balance of Plant (BOP)	Impact of failure or unavailability does not affect plant production or availability.	Waste water pumps	Offline, periodic condition monitoring	Bently Nevada Snapshot™

For the critical assets, the team reached the conclusion that they needed to both monitor and protect the machines. The risk and associated cost of a major failure was so high, they needed to be 100% sure that the machines could be shut down quickly to prevent catastrophic damage. They also decided that to proactively manage these assets, they needed to be able to have on-line access to the key condition assessment data rather than reactively gather the data using portable data acquisition equipment.

For the essential assets, the team decided that monitoring and protecting this equipment could not be justified. However, they wanted to spend their time managing the assets rather than collecting data. Thus, the conclusion was reached that automated data acquisition from permanently installed transducers was justifiable. This meant using a cost-effective multiplexing architecture that could continuously scan one asset after another.

For the BOP assets, the conclusion reached was that data collected periodically using a portable data collector (PDC) was the most suitable solution to manage this equipment.

While three distinct technologies were identified corresponding to each criticality classification, the plant wanted a single software platform to unify the systems. In addition, the ability to include process variable data was deemed essential in allowing personnel to diagnose and understand the cause/effect mechanisms of process-related machinery malfunctions.

After a careful evaluation, Mirant selected Bently Nevada hardware and System 1® software. Figure 2 provides an overview of the system as ultimately deployed.

System Implementation

Mirant elected to employ a turnkey approach and tasked GE with all aspects of the retrofit. The project was awarded in mid-2000 and the software/hardware arrived at site in October of that year.

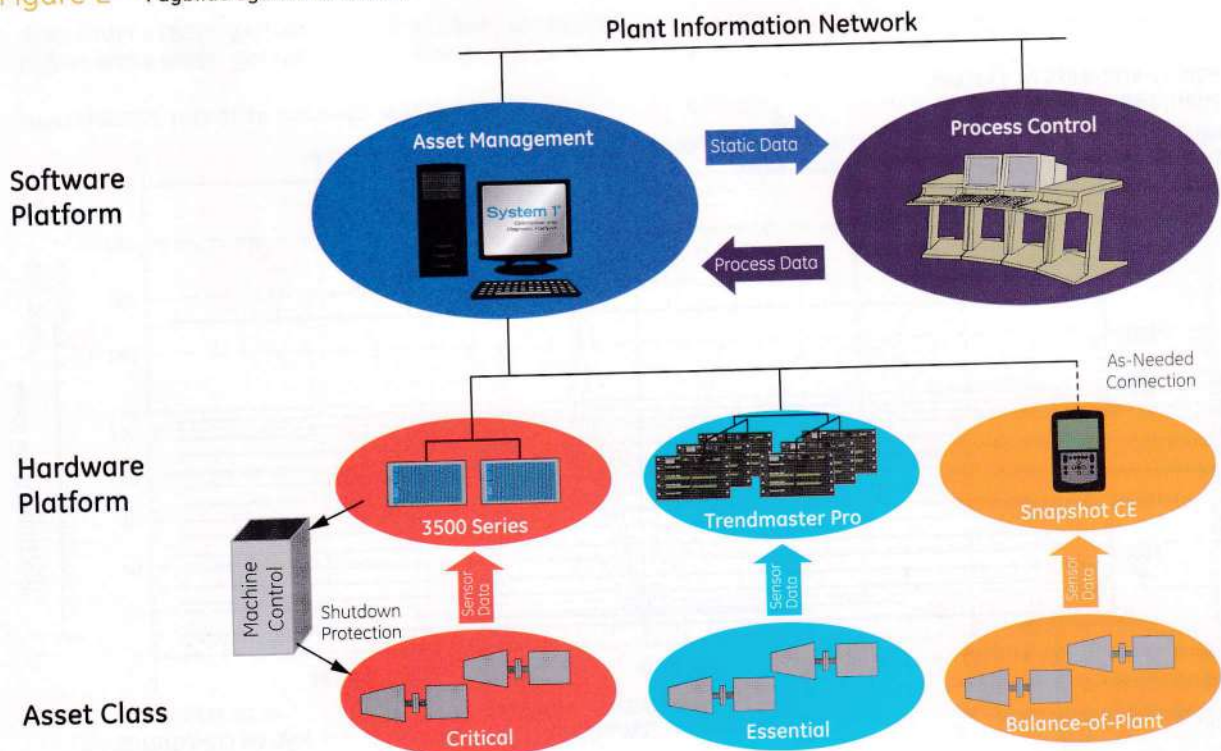
To ensure plant production would not be impacted, the Mirant performance engineering and GE installation teams carefully planned the retrofit around scheduled maintenance outages. This required detailed collaboration with Mirant's maintenance team to keep the retrofit activities from prolonging the outage durations that had already been established.

Key project milestones were as follows:

- **November 2000** – Cable installation commenced
- **December 2000** – Unit 1 boiler feed water pumps completed
- **February 2001** – Unit 2 steam turbine generator and boiler feed water pumps completed
- **May 2001** – Unit 1 shutdown for main turbine generator overhaul and inspection; installation of vibration probes on main turbine completed
- **June 2002** – Installation of vibration transducers on Unit 1 essential machines completed during annual inspection outage
- **August 2002** – Installation of vibration transducers on Unit 2 essential machines completed during annual inspection outage
- **September 2002** – Project completed

WHILE **THREE DISTINCT TECHNOLOGIES** WERE IDENTIFIED CORRESPONDING TO EACH CRITICALITY CLASSIFICATION, **THE PLANT WANTED** A SINGLE SOFTWARE PLATFORM **TO UNIFY THE SYSTEMS.**

Figure 2 – Pagbilao system overview.



Case History #1

Unit 2

Boiler Feed Pump 2B

On the morning of February 24, 2001, the Unit 2 steam-turbine-driven boiler feed pump was being returned to service at the tail end of a major 39-day planned maintenance outage. During this outage, the steam turbine had been fully overhauled under the supervision of the OEM's representative.

While starting and ramping the machine, the vibration amplitude at the pump inboard bearing started to increase until, at 3350 RPM, it reached the alarm set

point of 50 microns peak-to-peak. The operating speed for this pump is 5700 RPM, the machine runs below its first critical speed, and normal vibration levels are around 20 microns. The Performance Engineering Team was called in to investigate the high vibration.

Examination of the transient data plots available for the pump showed that the high vibration was predominantly synchronous with rotating speed (1X) as shown in Figure 3.

POINT: 2-BFPT-B BRG3Y $\angle 45^\circ$ Left
POINT: 2-BFPT-B BRG3Y $\angle 45^\circ$ Left

From 24FEB2001 14:59:23 To 24FEB2001 16:17:28 SU/SD
WINDOW: None SPECTRAL LINES: 512

3870 rpm

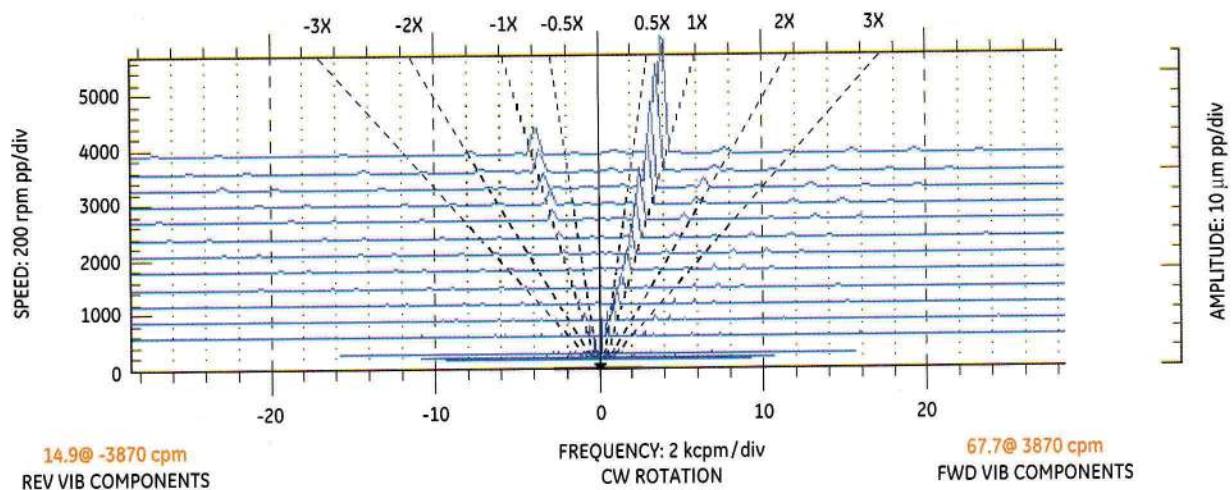


Figure 3 – Full spectrum cascade plot.

THERE APPEARED TO BE **A SUBSTANTIAL RADIAL FORCE** **PRESENT** AT THE COUPLING END OF THE PUMP.

Next, the orbit (Figure 5) and shaft centerline (Figure 6) plots were examined to ascertain whether any radial preload was present, such as may be caused by misalignment. The circular orbit shape and forward direction of precession were not indicative of any preload problems. Neither did the shaft centerline plot

suggest the presence of a preload as noted by the "healthy" attitude angle. The shaft rose in the bearing clearance as speed increased, and moved slightly to the left as expected for a shaft rotating in the clockwise direction, but was well away from the center of the bearing clearance where instabilities may occur.

Y: 2-BFPT-B-BRG3Y $\angle 45^\circ$ Left VECTOR: 73.9 μm pp $\angle 62^\circ$
 X: 2-BFPT-B-BRG3X $\angle 45^\circ$ Right VECTOR: 64.5 μm pp $\angle 176^\circ$

24FEB2001 16:17:28 SU/SD 1X UNCOMP

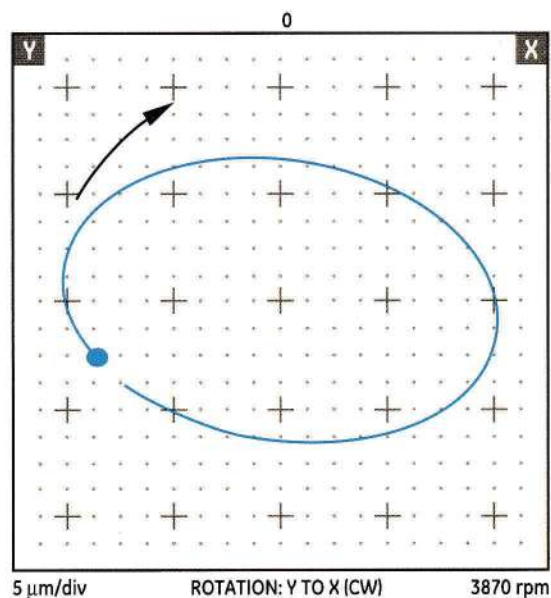


Figure 5 – Orbit.

POINT: 2-BFPT-B BRG3Y $\angle 45^\circ$ Left REF: -9.37 V -9.05
 POINT: 2-BFPT-B BRG3X $\angle 45^\circ$ Right REF: -9.48 V -9.30
 (-11.9, 44.7)
 24FEB2001@16:18:28
 FROM 24FEB2001 14:58:23 To 24FEB2001 16:18:28 SU/SD
 (not orbit or polar plot)

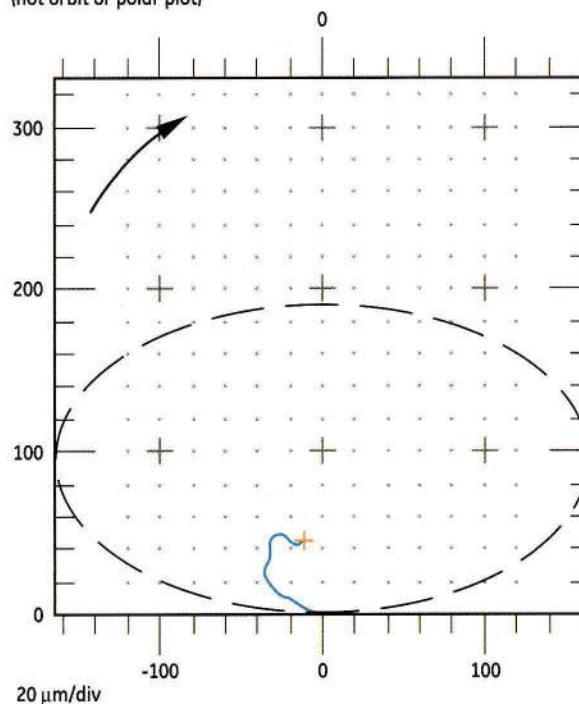
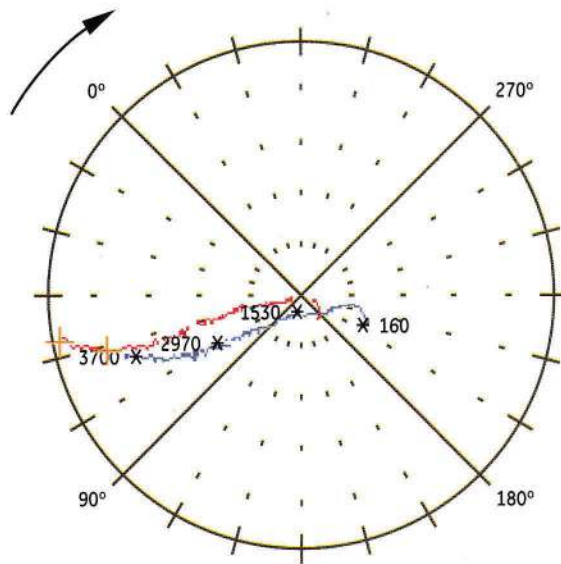
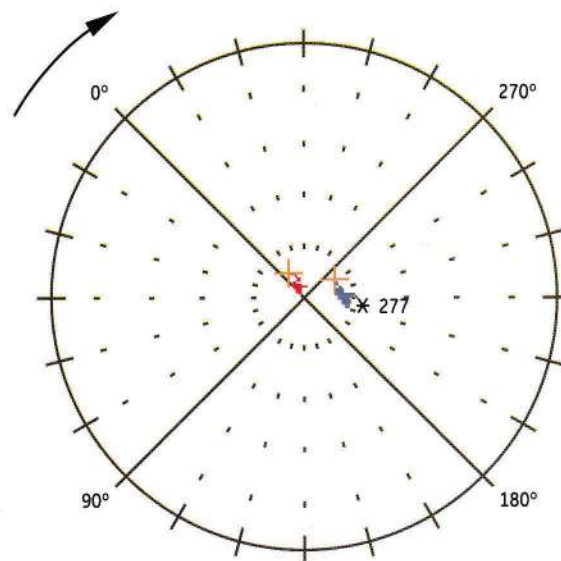


Figure 6 – Shaft centerline plot.



100 μm pp FULL SCALE



100 μm pp FULL SCALE

Figure 7 – Polar plots contrasting vibration before (top) and after (bottom) balancing.

Combined, this data suggested that the most probable cause of the increased vibration was unbalance force acting on the pump's coupling assembly.

Around 18:00 the same day, in-situ dynamic balancing was performed on the pump coupling, reducing the vibration level on the inboard bearing to 12 microns. Unit 2 was successfully returned to full service availability one hour ahead of the original schedule.

Figure 7 shows the 1X polar plots obtained from the inboard bearing, illustrating the pre- and post-balancing results.

Further investigation of the vibration problem revealed that the root cause of the unbalance force was eccentricity in the bore of the coupling hub. A replacement coupling was subsequently installed at the first available opportunity.

Economic Impact

In this case history, Unit 2 was nearing the end of its 39-day planned outage. Because the pump problem was discovered two days before the end of the outage, there was still time to resolve the problem without impacting the start-up schedule and declaration of full plant availability. Had there been no machinery management system in place, the problem on the pump would have delayed the declaration of unit full-load availability by approximately 60 hours while the cause of the high vibration was identified and steps taken to rectify it. Proactive intervention prevented this delay that would have incurred contract penalties of \$90,000 due to de-rated output. It also averted the cost of potential damage to the machine.

Case History #2

Unit 1

Boiler Feed Pump 1B

In December 2002, during routine analysis of this pump's condition, the Performance Engineering team noticed periodic "spiking" on the vibration trends from the X and Y probes on the pump's outboard bearing. Historic vibration levels on the pump were around 25 microns peak to peak (pp); however, these spikes were between 34 and 40 microns – significant deviations from normal (Figure 8). While not considered critical at that point in time, the team was concerned

as any failure of the pump would directly impact the availability of Unit 1.

Initial investigation of the problem revealed that the spiking was occurring predominantly when the pump was operating at idling speed (3700 – 3900 RPM); when the pump was under load (3900 – 4500 RPM), the spiking was not present. Typical duration of the vibration spike was brief – only two to three seconds.

Brg4Y Rtr Vbrg	— /45° Left	Direct	15DEC2002 21:40:13	36 µm pp	3970 rpm
BFPT 1A	From 10DEC2002 08:00:00 To 22DEC2002 16:00:00			Historical	
Brg4X Rtr Vbrg	— /45° Right	Direct	15DEC2002 21:40:12	25 µm pp	3970 rpm
BFPT 1A	From 10DEC2002 08:00:00 To 22DEC2002 16:00:00			Historical	

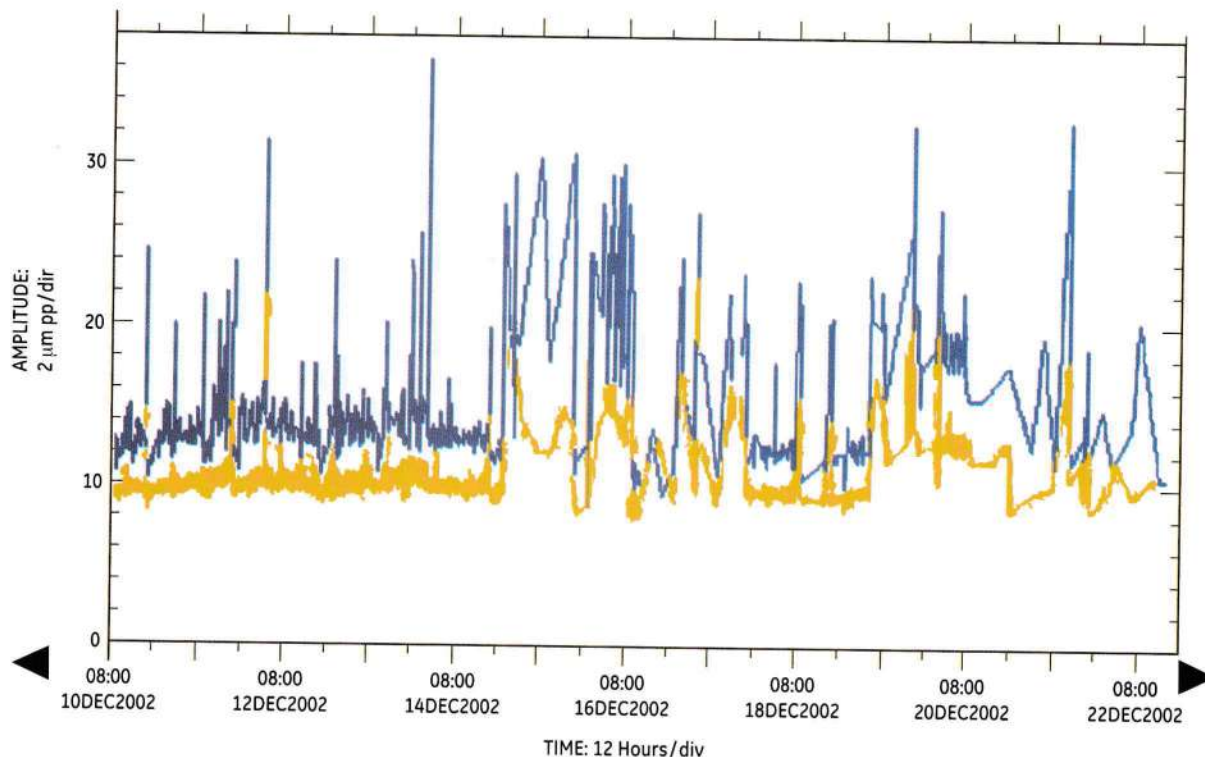


Figure 8 – Vibration trend plot of pump outboard bearing showing intermittent "spiking" above 20 µm.

Further investigation revealed that the spikes were the result of substantial sub-synchronous vibration at 56% of the pump's running speed (Figure 9).

While it was known that harmonics in the 0.5X region of the vibration spectrum can be indicative of mechanical looseness, the exact cause of the sub-synchronous components was still not clear. The pump was closely monitored over the following weeks and although the spikes continued to occur, their magnitude stayed in

the same range and the situation was considered to be manageable. No further action was taken for approximately four months.

In April, 2003, however, the pump was operating at around 4200 RPM when the vibration magnitude suddenly increased from 29 to 72 microns (Figure 10) and remained at this level, well above the ALERT alarm limit and very close to the trip setting of 81 microns. A maintenance outage was scheduled to allow the

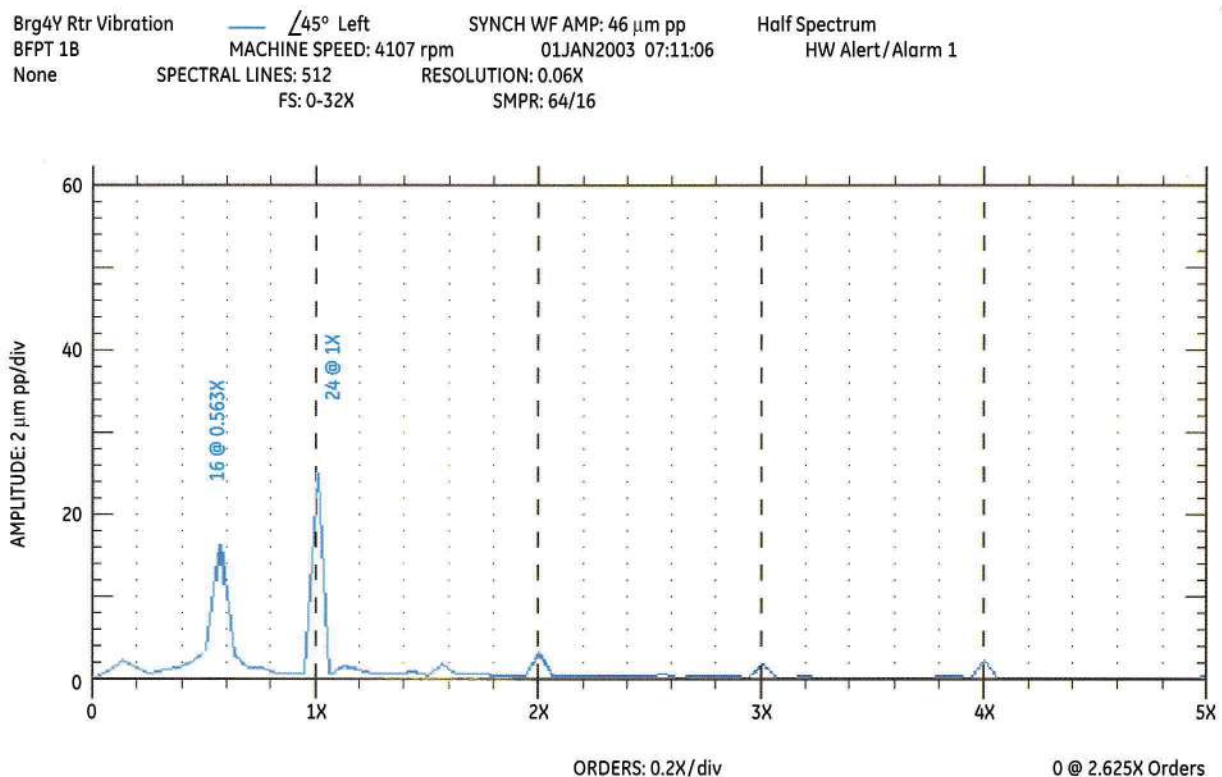


Figure 9 – Half-spectrum from pump outboard bearing Y probe.

outboard bearing to be opened for inspection. A recommendation from the Performance Engineering Team instructed the maintenance team to check for signs of mechanical looseness in the bearing assembly. The subsequent inspection revealed wear on the anti-rotation pin of both the upper and lower half bearing shells as shown in Figure 11.

However, this wear was considered the result of vibration rather than the cause; subsequent inspection revealed the true root cause: excessive clearance between the bearing and its housing. Because exces-

sive clearance reduces the mechanical stiffness, increased shaft vibration occurs. This was consistent with the observed data.

As a temporary expedient, the bearing shell was shimmed by 0.0254mm to reduce the clearance and the pump was successfully returned to service. Later, during a planned outage in October 2003, a more permanent repair was performed involving re-machining to restore the correct interference between housing and bearing per the pump's design specifications.

Brg4Y Rtr Vbrg	— $\angle 45^\circ$ Left	Direct	18APR2003 19:14:33	77 μm pp	4207 rpm
BFPT 1B	From 18APR2003 18:00:00 To 18APR2003 20:00:00			Historical	
Brg4X Rtr Vbrg	— $\angle 45^\circ$ Right	Direct	18APR2003 19:14:35	50 μm pp	4207 rpm
BFPT 1B	From 18APR2003 18:00:00 To 18APR2003 20:00:00			Historical	

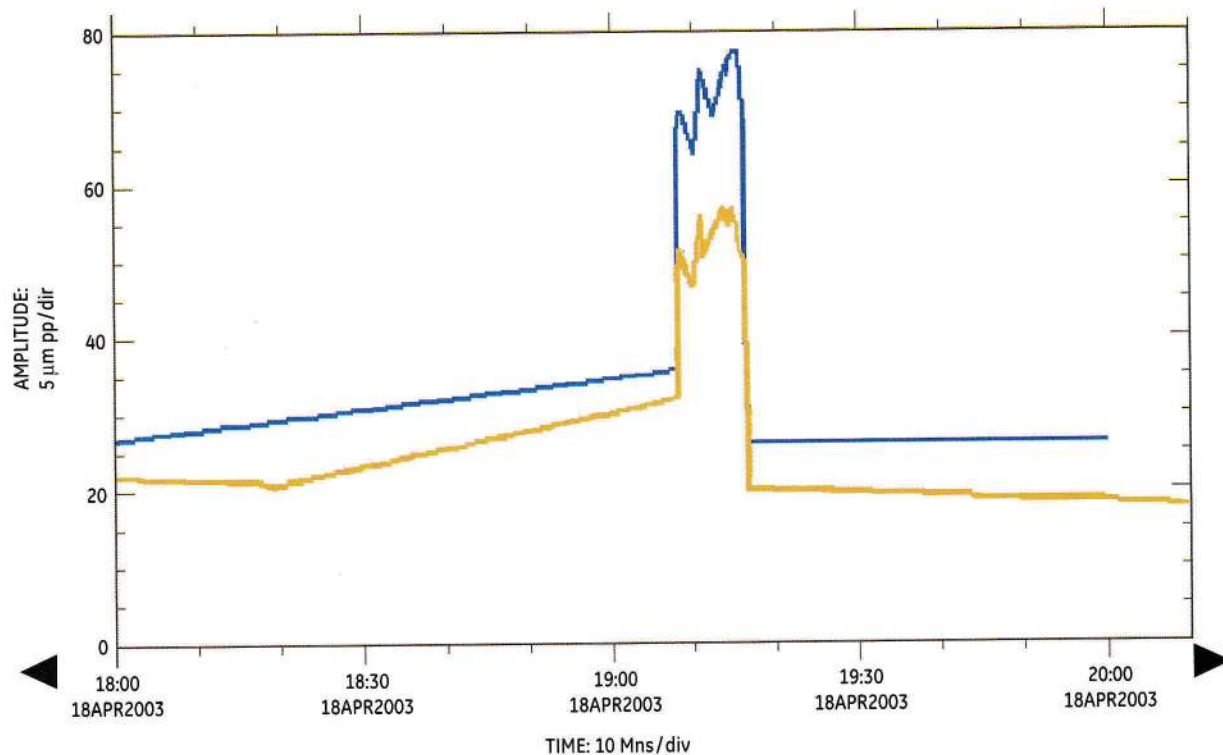


Figure 10 – Vibration trend of pump outboard bearing.

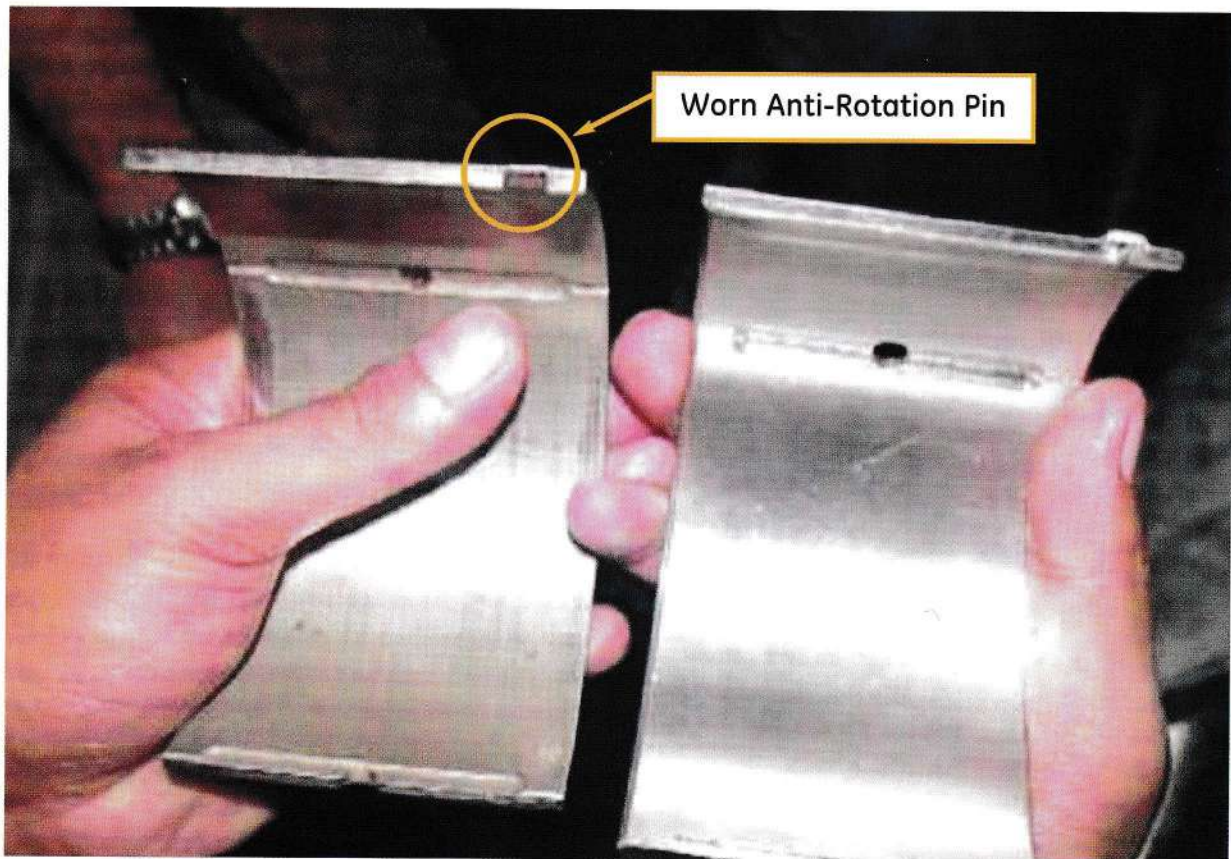


Figure 11 – Old and new bearings.

Economic Impact

The loss of a steam-turbine-driven boiler feed pump at Pagbilao has a significant impact on plant performance: plant output is reduced and energy consumption is increased when the spare electric-drive pump unit has to be put into service. By allowing operators to run the pump at full capacity while closely monitoring its condition between December 2002 and April 2003, the plant avoided a forced outage until conditions deteriorated enough to warrant an inspection.

When an inspection was finally called for, the data collected by the condition monitoring system allowed the maintenance team to focus on the appropriate parts of the machine train rather than a more extensive disassembly and inspection. Further, rather than simply replacing the bearing shells as may have been indicated by only a visual inspection, the vibration data helped ensure that the machine was returned to service only after the real root cause was understood and addressed. Had this data not been in place, the machine would likely have been restarted without

addressing the root cause, the replacement bearing shells would have continued to vibrate excessively, and one or more repetitions of shutdown/replacement would have likely ensued. Instead, the team was able to clearly understand the problem, implement a short-term corrective action that was effective, and allow the machine to operate until its next planned outage.

Summary and Conclusions

There have been many other examples at Pagbilao where the Performance Engineering team has used the installed System 1 infrastructure to manage the plant's rotating equipment assets. Internal calculations by Mirant showed that the entire cost of the system was recovered in the first 20 months after installation.

As shown in these case histories, the system allowed the plant to distinguish major problems from minor problems, defer inspections until regularly scheduled outages, and closely monitor machinery problems without interrupting plant production. Even though the machinery "saves" have been of a more routine variety rather than dramatic multi-million dollar events, in the four years since the system was installed, a clear pattern has emerged.

First, the main turbine generator (TG) units have proven to be very reliable and largely trouble-free. Mirant uses their System 1 software on these units primarily to maintain a close watch for any change from the status quo while compiling an extremely valuable database of "normal" machine behavior. Second, although the main TG sets have run without incident, the other assets addressed by the condition monitoring system have not been so fortunate. The existence of good condition monitoring data has been indispensable in isolating and

correcting faults on these assets. In particular, the boiler feed pumps and boiler fans have been sources of mechanical problems, along with several essential assets.

Another noteworthy observation is that Pagbilao is a relatively new power station – it only went into full service in 1996. It is expected that as the station ages, additional value will be realized from the system, particularly when the time approaches for major overhauls on the main TG units. Experience on similar plants has shown that only by knowing the long-term condition of the main units is it possible to accurately define the maintenance that needs to be performed when major overhauls are due. The alternative is to carry out the full list of maintenance activities recommended by the OEM, meaning extended out-of-service periods and higher costs for activities that are performed "just in case" rather than because the condition warrants it. Pagbilao now has the data to make informed maintenance decisions. 



A technician gathering data from a cooling water pump at Mirant Philippines' Pagbilao Generating Station.

1900/65 General Purpose Equipment Monitor Adds Modbus® Ethernet Connectivity

Fritz Schweigert

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Our recently released (January 2005) Bently Nevada™ 1900/65 General Purpose Equipment Monitor has already established itself as a very popular offering with customers. The addition of Modbus® connectivity makes it even more appealing.

Designed as a flexible, cost-effective solution for customers wishing to continuously monitor and protect essential and general purpose assets, the 1900/65 now allows users to transmit a broad range of static variables collected by the monitor along with alarm statuses and event list data. Using the optional Modbus gateway that is completely integral to the 1900/65, data can be supplied to a wide variety of plant automation, condition monitoring, and information platforms such as Distributed Control Systems (DCSs), Programmable Logic Controllers (PLCs), Supervisory Control and Data Acquisition (SCADA) Systems, and our own System 1® Optimization and Diagnostic Software. Special consideration has been given to ease-of-use in the interface by incorporating features such as dynamic Modbus memory mapping, allowing integrators more flexibility in how registers are assigned and used. The result is more efficient access to 1900/65 data while minimizing programming and communications overhead. Configuration data for both the monitor and the interface can be exported in Comma Separated Variable (CSV) format, making it easy to document your installation.

The 1900/65 is designed for installation near the equipment it protects, reducing wiring costs. To provide the necessary data back to the control room, the monitor's Modbus gateway feature can be used over a wired or wireless Ethernet connection back to the control system. Because the 1900/65 is available with hazardous area approvals, users have additional flexibility in mounting the device near the equipment it monitors – particularly



The 1900/65 Monitor is now available with optional Modbus® gateway functionality, allowing Ethernet connectivity to plant control and automation systems.

important for refineries, chemical plants, and other hydrocarbon processing facilities where flammable atmospheres are present.

A small, flexible, multi-channel monitoring system, the 1900/65 provides channel density and connectivity characteristics usually only found in much larger, more expensive systems. In addition to overall vibration levels and alarms, users can custom configure the monitor to provide specific signal conditioning, alarm types, and alarm logic tailored to each individual machine type and application. Such configuration allows "smarter" alarming, helping users quickly determine the right corrective actions when a machinery upset occurs. Coupled with its new digital connectivity, users have an even more powerful platform for addressing general purpose machinery, allowing them to get the data they need, when they need it, and cost-effectively integrate it with their plant's control and information infrastructure.

You can learn more about the 1900/65 General Equipment Monitor by consulting your nearest sales professional, or by visiting www.gepower.com/o&c/bently and navigating to Products>>Monitoring Systems. 

Sonic Horn Monitoring

For Selective Catalytic Reduction (SCR) Applications

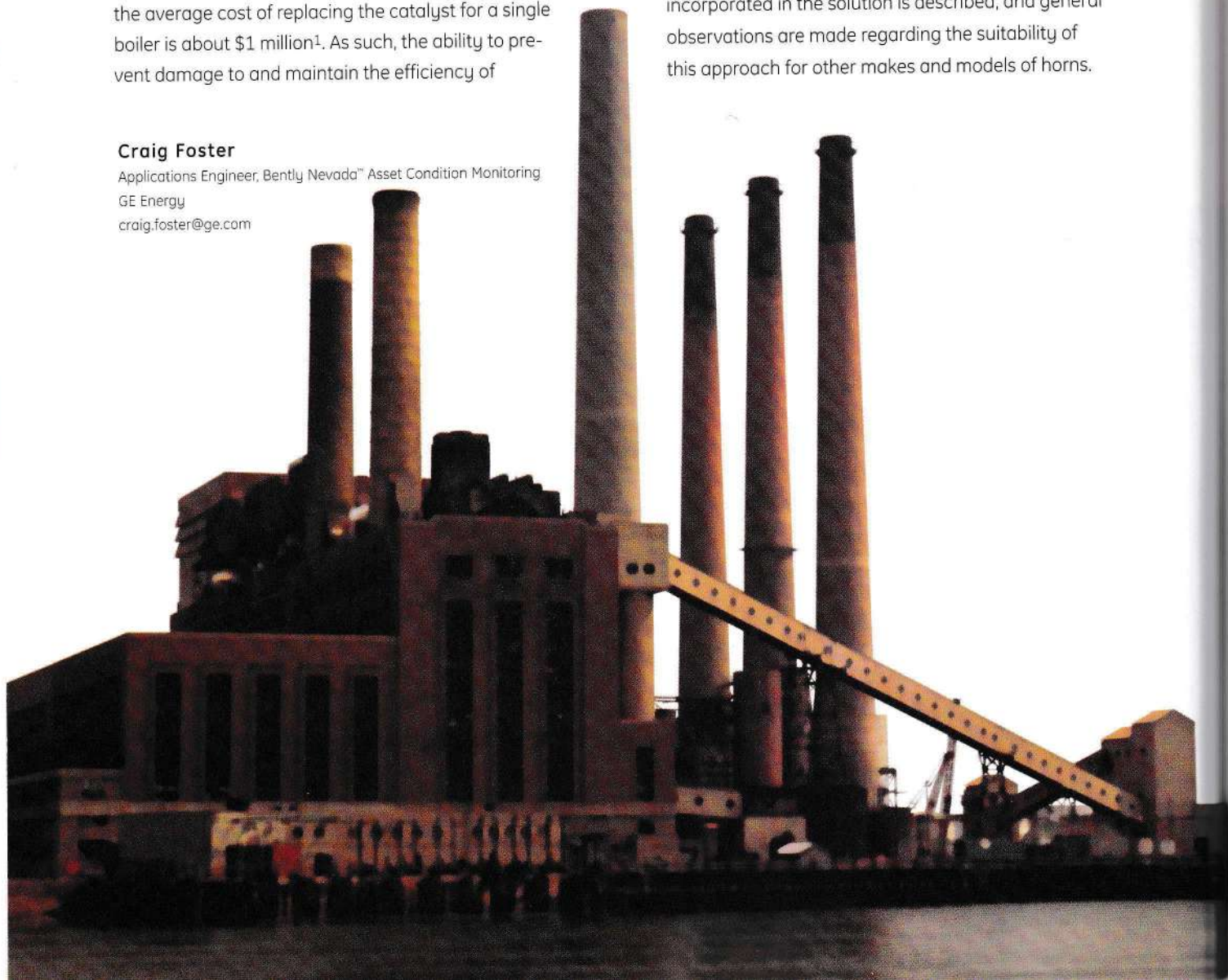
The sonic (or acoustic) horn is an essential component of the Selective Catalytic Reduction (SCR) process that is becoming the method of choice to reduce nitrogen oxides (NO_x) emissions at coal-fired power plants. SCR has been shown to be the most efficient means of NO_x reduction. Consequently, plant operators look to SCR as their tool for compliance with the Clear Skies Act, first submitted to Congress in 2002. This act levies fines on power plants producing greater than their share of NO_x . In addition to fines, the average cost of replacing the catalyst for a single boiler is about \$1 million¹. As such, the ability to prevent damage to and maintain the efficiency of

catalyst is essential, and the use of sonic horns has emerged as the preferred means for cleaning the catalyst.

To ensure the ongoing proper operation of these sonic devices, horn manufacturers and end users agree that monitoring the horn for proper operation is advisable. This article explores a solution developed for a specific make and model of sonic horn, the BHA Powerwave® D-75. The monitoring methodology incorporated in the solution is described, and general observations are made regarding the suitability of this approach for other makes and models of horns.

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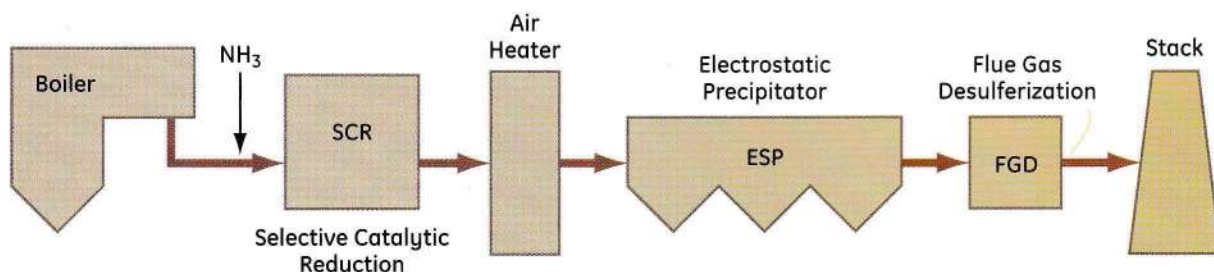


Figure 1 – Typical boiler flue gas flow-through system with an SCR installed.

SCR Process Is Similar To Automotive Catalytic Converters

A notable similarity between one form of SCR and automotive catalytic converters is the extruded honeycomb that carries the catalyst. This catalyst promotes the desired chemical reaction that results in a 50 to 90% reduction of the NO_x emissions. The major differences are the catalyst material (homogeneous titanium-tungsten-vanadium Ti-W-V in the case of most coal-fired power plants), the injection of ammonia (a critical component of the chemical reaction), and the volume of exhaust that the SCR must process. The large volume requires a substantially larger and more expensive catalyst. Therefore, the system has been designed to operate at high efficiency to maximize the operators' return on their investment. Figures 1 and 2 show a typical configuration of these components, and the interested reader can find additional information in a paper presented at an EPA/EPRI symposium on NO_x control².

**THIS VERY IMPORTANT
FUNCTION OF THE HORN
HAS DRIVEN PLANT
OPERATORS TO BECOME VERY
INTERESTED IN THE HORN'S
PERFORMANCE ON A
CONTINUAL BASIS.**

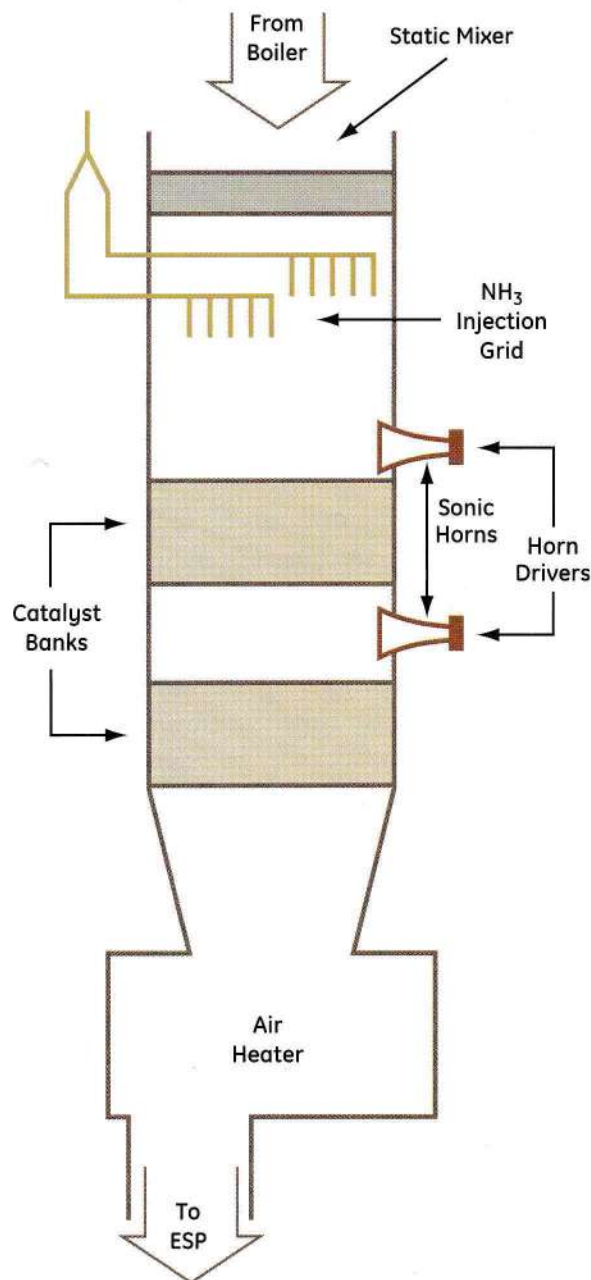


Figure 2 – Flue gas flow through typical SCR system.

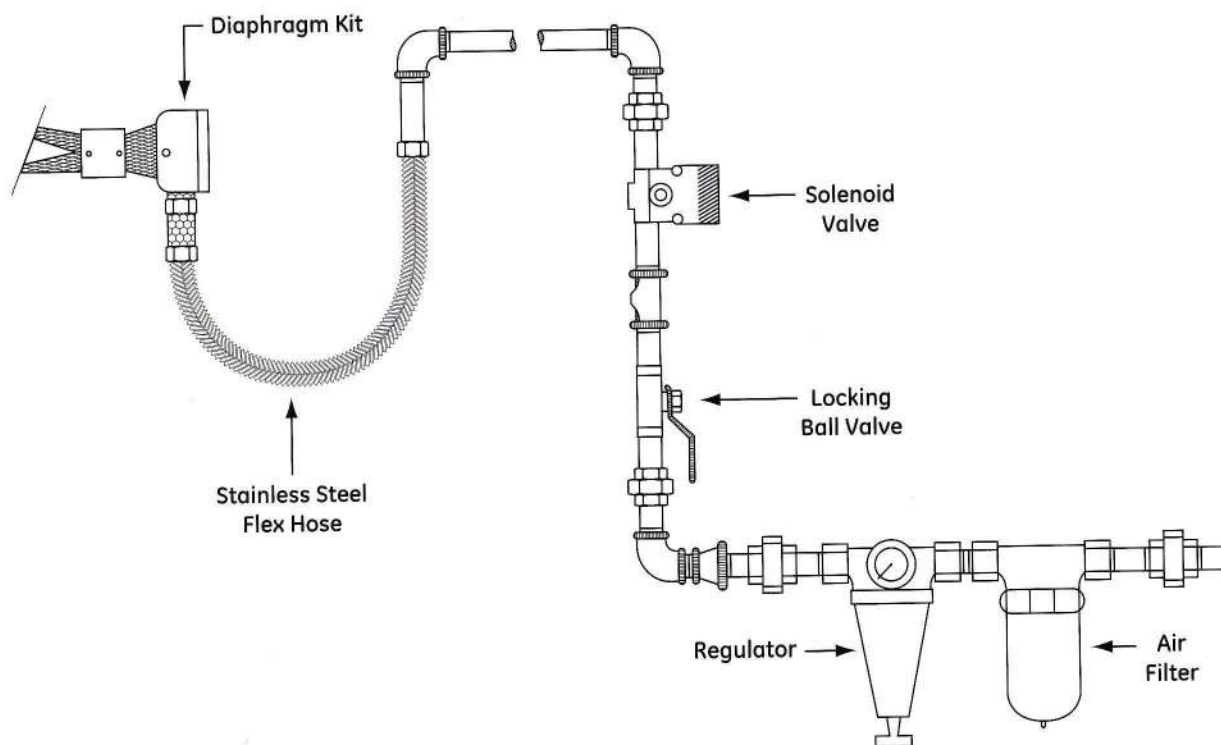
Sonic Horn Cleans Catalyst, Increasing Its Efficiency

The horn's sole purpose is to clean the catalyst using acoustic vibrations. Operating (typically one at a time) for ten seconds every ten minutes, the horns vibrate particles and buildup on the catalyst banks. This causes the debris to fluidize, and it is carried away by the flue gas stream. This prevents physical degradation of the catalyst and allows the SCR chemical reaction to proceed more efficiently. This very important function of the horn has driven plant operators to become very interested in the horn's performance on a continual basis.

The horns are driven using high-pressure air (typically 80-90 psi at 60-70 scfm) normally available on-site (Figure 3). The high-pressure air is used to vibrate a diaphragm within the horn driver. The particular horn

under test (Figure 4) is the Powerwave® D-75 from BHA, but any horn of similar construction can potentially be addressed by the monitoring methodology presented later in this article. Initially, the diaphragm is biased against the raised primary seat, sealing plenum A from plenum B. As air enters through the inlet, the pressure rises in plenum B until it deflects the diaphragm away from the primary seat, allowing the air to escape to plenum A. The resulting pressure drop in plenum B allows the diaphragm to reseat itself. The air that escapes to plenum A continues down through the bell of the horn, into the flue gas stream, and is directed at the catalyst. Meanwhile, the process in the driver repeats itself, and the diaphragm oscillates at the characteristic frequency of the horn. Since plenum C is vented, it remains at atmospheric pressure, even though its volume is changing during diaphragm deflection.

Figure 3 – Typical air supply to SCR horn.



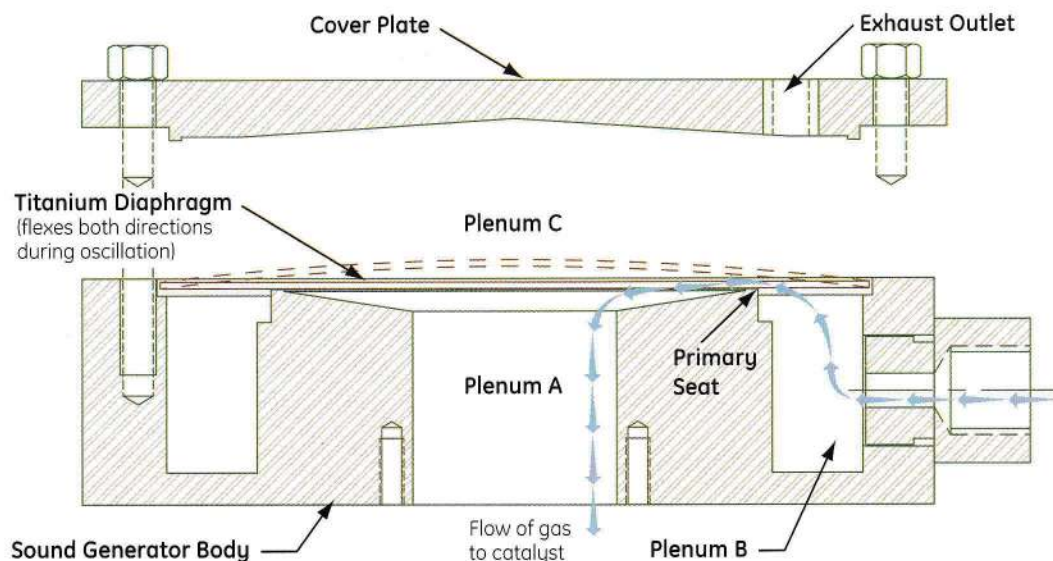


Figure 4 – D-Series Sound Generator cross section. The primary seat extends above the mounting surface for the cover plate and seats against the diaphragm as the cover plate is tightened down. As the diaphragm oscillates, gas flows from plenum B to plenum A.

Horn Problems Identified with Vibration Transducer

There are two major problems that can occur in the horn. The most important problem is low output amplitude, since it leads to physical degradation of the catalyst. Low output has a multitude of root causes, including low air supply pressure, clogged air supply line, worn diaphragm, worn primary seat, worn or damaged backing cap, solenoid valve overheating, solenoid valve not fully opening, and debris build-up in horn driver or bell. The second problem is a ruptured diaphragm. Although there is reasonably high potential for a rupture to also cause low output, this is not always the case, and, therefore, this problem must be considered separately. Since both problems affect the vibration of the horn, it was reasoned that a vibration transducer and appropriate signal conditioning would be a potentially reliable method of monitoring the horn for symptoms of these malfunctions.

To test this hypothesis, a seismic vibration transducer was mounted on the back of the horn driver for a

BHA Powerwave® D-75. The transducer's frequency range must encompass both the base frequency of the horn (nominally, 75 Hz for the D-75) along with a reasonable range of sub- and super-harmonics. The Bently Nevada™ Velomitor® transducer met these requirements and was selected as a suitable sensor for this application.

Low output is a straightforward measurement, detected as a lower-than-normal amplitude for the base (fundamental) frequency component. Low output can also be detected by a decrease in the RMS amplitude of the overall (unfiltered) transducer output and/or by examining the spectrum of the vibration waveform.

The ability to differentiate a ruptured diaphragm from other causes of low output was noted in the test data by the following characteristics of the vibration spectrum:

1. The amplitude of the fundamental frequency initially decreased during early stages of diaphragm failure. As the failure severity progressed, the fundamental amplitude increased, as with other low-output causes.

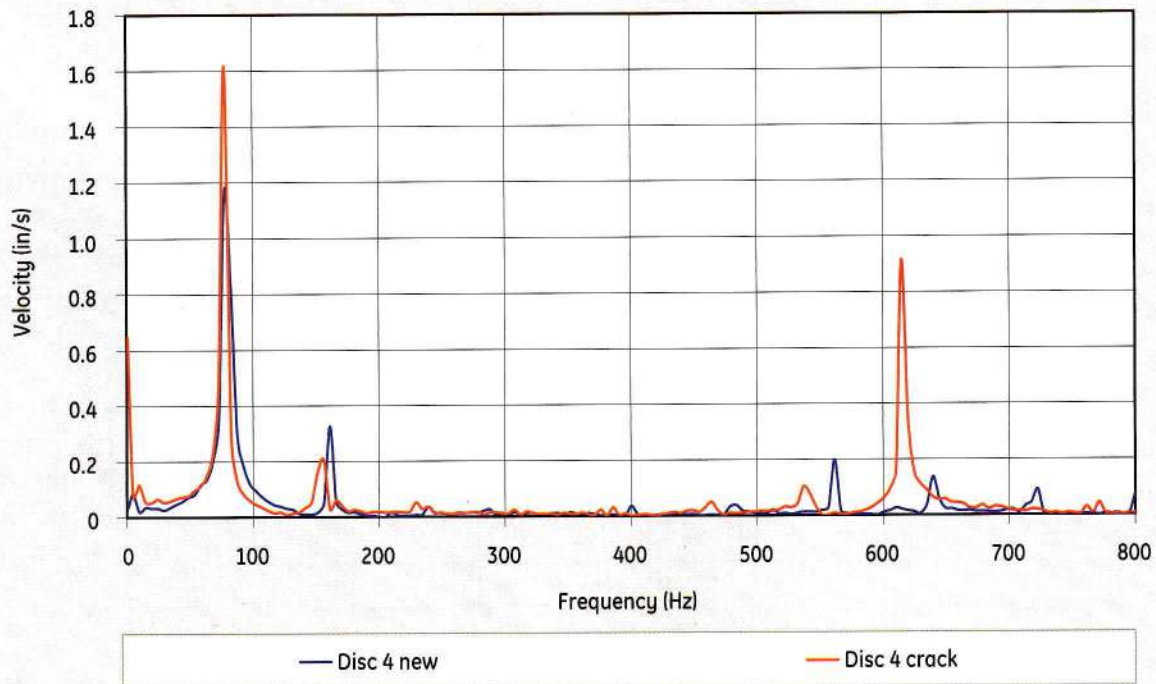


Figure 5 – FFT of Velomitor transducer data before and after diaphragm rupture showing dramatic change in amplitude of 8th harmonic.

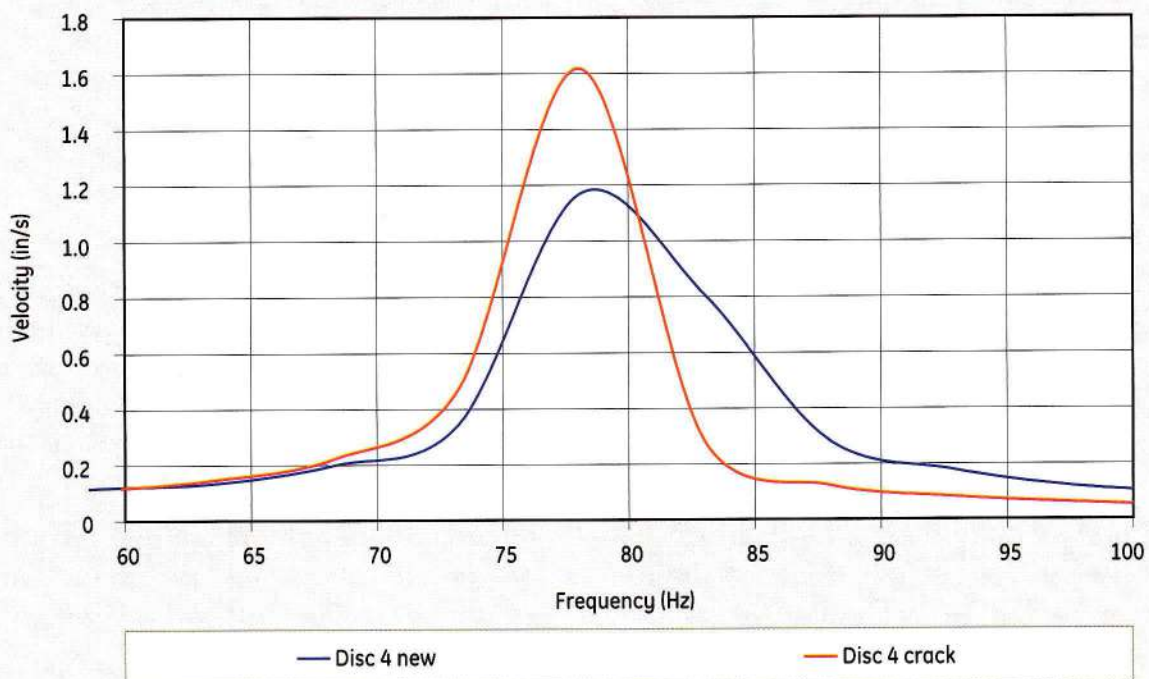


Figure 6 – Zoomed FFT of Velomitor data before and after diaphragm rupture. An increase in amplitude of the fundamental frequency will typically appear before other spectrum changes, signifying the early stages of rupture.

2. The amplitude of a specific harmonic showed dramatic changes. In the case of the D-75, this was the 8th harmonic.

Figures 5 and 6 show the broadband and narrowband spectrum, respectively, for a single diaphragm before and after rupturing. The test was repeated on three additional diaphragms and showed a repeatable pattern, allowing the Velomitor transducer to differentiate between proper and improper horn operation as well as detect specific symptoms indicative of a rupture.

Figure 5 clearly illustrates the differences in the 8th harmonic vibration component, while Figure 6 shows the amplitude and frequency differences in the fundamental component. In addition to the rupture testing, tests conducted with three intact diaphragms showed that changes in the horn's sonic output were indeed correlated to the Velomitor transducer reading.

Bently Nevada 3500 Series Solutions

Using a Bently Nevada 3500 Series Machinery Protection System with the appropriate vibration and process monitors allows the operator to access all the information from the SCR systems while remaining in the control room. This solution uses standard, off-the-shelf hardware, configured to alarm on the overall and filtered frequencies of interest, allowing both types of malfunctions to be detected. However, it should be noted that the testing in this article was confined to a specific make and model of sonic horn. While the underlying monitoring methodology is sound, customers interested in applying this measurement to other types of sonic horns are encouraged to work with our custom applications team. Extrapolation of this solution to other horn types requires a good understanding of a horn's particular fundamental frequency and characteristic failure harmonics, both of which our custom applications team can address.

Because it is very typical to find the 3500 Series System in most power generation plants for monitoring their main turbine/generators, the ability to include sonic horn monitoring in the same platform is particularly convenient and cost-effective. The 3500 System can also be easily interfaced to GE's System 1[®] Optimization and Diagnostic Software. This software provides additional capabilities for assessing mechanical health by allowing users to trend specific frequency components, conduct detailed waveform and spectral analysis, add additional levels of overall and frequency-banded alarms, and generate custom rules that permit automated diagnostics, fault-identification, and corrective action notifications.

Summary

This article has described a method for monitoring the proper operation of the BHA Powerwave[®] D-75 sonic horn using an appropriate vibration transducer and signal conditioning in the Bently Nevada 3500 Series Monitoring System. With the assistance of our custom applications team, it is believed that this approach can be successfully applied to other makes and models of sonic horns, using standard, off-the-shelf hardware, and appropriately configured monitor settings. It demonstrates the ability of our custom applications team to address customer requirements for important plant assets that fall outside the rotating machinery realm, while adhering to sound, proven engineering principles. Interested customers with sonic horn or other assets warranting continuous condition monitoring are encouraged to contact their nearest sales professional for assistance. 

1. Maier, Herwig and Spokoyny, Felix. "Successful Experience with In-Situ Regeneration of SCR Catalyst in Coal Fired Applications" EnBW Ingenieure GmbH, Stuttgart Germany/Hera LLC, Lake Forest, CA. June 2000.
2. Pritchard, Scot et. al. "Optimizing SCR Catalyst Design and Performance for Coal Fired Boilers" Presented: EPA/EPRI Joint Symposium on Stationary Combustion NO_x Control, 1995.

Synopsis of Savings

Remote Diagnostics Avert \$900,000 in Lost Production

A 400 MW steam turbine generator at a coal-fired power plant had been running smoothly for nine months since the last major outage, and was fitted with a Bently Nevada™ machinery protection system connected to System 1® software. However, following a boiler trip and restart, the machine train began to exhibit sustained high vibration at one of the turbine bearings. Because these vibration levels were above alarm limits, plant personnel were concerned about the health of the turbine.

The customer had previously contracted with our asset care team to support the site via remote machinery diagnostics as well as ongoing monitoring system optimization. This allowed our on-call machinery diagnostics engineer to immediately access the System 1 database remotely and begin diagnosing the problem. Transient data collected during the boiler trip and subsequent restart were available in the system, in addition to continuous steady state data showing the sustained high vibration following the startup. Armed with this comprehensive data, our machinery diagnostics engineers were able to determine that looseness within one of the tilt-pad bearing assemblies was the most likely cause of the high vibration.

Based on this diagnosis, continued short-term operation of the unit was considered reasonable and plant personnel were able to defer downtime for inspection and correction of the bearing assembly until a more convenient opportunity. This enabled the plant to avert a costly unplanned outage which would have cost 900,000 USD in lost generating capacity. Without the information delivered by System 1 software, and the expertise to interpret this data, the customer would have shut the machine down for inspection under the concern that continued operation might lead to catastrophic failure. In addition, the remote access capability allowed our

machinery diagnostics personnel to diagnose the problem without incurring the time and expense involved in traveling to the plant site.

It Pays to Believe That Trend

Two recycle gas compressors in a large petrochemical complex are fitted with Bently Nevada™ 3500 Series Machinery Protection Systems and associated condition monitoring software. The compressors are critical to plant production – if one fails, the plant is only able to operate at 50% capacity. Over a period of several months, vibration levels on the machine trended upward, eventually increasing to 400% of original levels, but still below the alarm settings. Operations was reluctant to stop the machine, but at the insistence of the maintenance team, the compressor was finally brought down for an inspection out of concern that severe damage was imminent if operation continued. Inspection revealed heavy deposits at three of the four impeller stages, along with dents on the #1 impeller thought to be due to “hammering.” A loose bolt was also found in the casing. A spare rotor was installed during a three-day turnaround and the compressor was returned to service, exhibiting normal vibration levels. The plant estimates that imminent failure would have indeed occurred had they not heeded the condition information provided by their system, and the turnaround would have conservatively taken 10-15 days, rather than three. Estimated savings: 20MM USD.

When a Rub is OK

A large thermal power plant instruments its main turbine-generator set (a large 9-bearing train) with Bently Nevada™ machinery protection systems and newly installed condition monitoring software. While one of our machinery diagnostics engineers was on-site providing some product overview training, he learned that the machine was experiencing “noise problems on

the exciter" and could not be taken to full load. According to plant management, this was a source of considerable concern and no one had been able to identify the root cause. The on-site machinery diagnostics engineer used the opportunity to access the machine's Bently Nevada™ condition monitoring software and examine the data. He rapidly diagnosed the problem as a seal rub, advising that the newly installed seal was simply "wearing in" and the elevated vibration levels would eventually subside as the seal clearances opened. 30 minutes later, the vibration indeed subsided, decreasing from 6 mils peak-peak to around 1 mil. By understanding the root cause of the vibration and why it subsided, the plant was able to bring the unit to full load (and full profit) without the need for an inspection and attendant loss of production. This single event more than paid for the entire system during the first few hours of its use.

Big Saves Even Before Fully Commissioned

A catastrophic pump failure at a large petrochemical facility had resulted in a fire totaling more than 12MM USD in losses. This led the customer to deploy Bently Nevada Trendmaster® systems at several of its locations, providing online condition monitoring for hundreds of pumps and other equipment assets to help avert a recurrence of such events. The company's strategy was to have operators play an active role in the use of the system, and they were trained in its use even before the system was fully deployed and commissioned.

The project spanned several months, but even as the very first pumps were brought online with vibration/temperature measurements, the system began providing value. Operators conducting their normal rounds of the process unit stopped by the shelter housing the Trendmaster computer, allowing them to check on readings from the initially added pumps. To their surprise, one

of the crude pumps was in the highest level of vibration alarm, and after verifying the reading, a spare pump was immediately brought online. When the pump that had been removed from service was disassembled and inspected, it was obvious that catastrophic failure was imminent – only a few minutes away.

Bolstered by this early machine "save," the project schedule was altered to rapidly integrate alarms from the Trendmaster system into the process control system, giving operators visibility of the Trendmaster system at all times without the need to leave the control room. Two days after integrating these alarms, another pump went into an alarm condition, and a spare was again brought online. The offending pump was found to have a damaged sleeve bearing. Within the same week, another pump went into alarm and a spare was brought into service. The pump's rolling element bearing was found to have a severely damaged cage and was very near failure. Several weeks later, a failing motor bearing was flagged during a weekend, and personnel were able to diagnose the problem remotely, confirming the need to bring a spare unit online. Subsequent inspection revealed significant spalling on the bearing's outer race.

The temperature monitoring likewise proved valuable, as it helped identify several pumps that required additional coolers and/or piping alterations, in addition to alerting operators to clogged water lines. When these lines clog, pumps that normally run at 150 °F can rise to 220 °F within minutes. With the Trendmaster system, such conditions are alarmed and immediate action can be taken. According to operators, this level of surveillance can't even be approached without the system and, in their words, "It's like having an Assistant Operator standing next to each pump 24 hours per day. Catastrophic pump failure prevention was the basis for justification of this system and before we even had it commissioned, it paid off big time." 

New Training, New Performance Optimization Solution

Performance Cycle Partnerships

While many combined-cycle and cogeneration facilities understand the value in optimizing thermodynamic and operational performance, achieving it is not a simple challenge. Compounding the operational challenge, plants often lack information to perform timely maintenance on key equipment to maintain rated performance. Losses from wasted fuel, contract penalties, and reactive maintenance quickly add up, eroding plant profitability. As a result, very few plants actually obtain all the heat rate and generation improvements to which their processes entitle them.

Our new Performance Cycle Partnerships are designed to give plants the benefits of optimized heat rate and generation, without having to build such a program unassisted. As an integrated "turnkey" package of services, training, software, and closed-loop controls, it implements and sustains optimum thermo-economic performance – at a guaranteed level based on your plant's entitlement potential. As a service, you needn't worry yourself with installing and configuring software, validating sensors, or interpreting data. We partner with



you to deliver the right performance improvements you need, tailored to your economic environment.

Learn more about this innovative new service in an informative brochure. Go to www.gepower.com/orbit, use the menu option "obtain literature," and select the 3rd Quarter 2005 issue from the drop-down list. There, you can download an electronic copy or request a printed copy. You may also obtain literature using the printed Reader Service Card attached to this issue of ORBIT.

Computer-Based Training

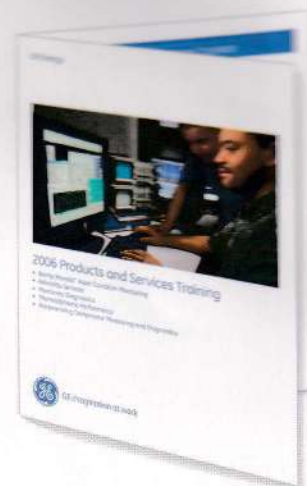
While there is often no substitute for hands-on, instructor-led training, busy schedules, and workplace urgencies don't always leave time for travel and traditional "stand and deliver" training. To assist our customers in optimizing their training and travel budgets, we are pleased to offer the convenience of self-paced, computer-based training (cbt) for several of our courses. The fundamentals of vibration monitoring instruments and data types are covered in our Data Acquisition cbt, providing the prerequisite material for many of our curriculum tracks. Our Machine Library software is another cbt that customers find particularly valuable, providing an excellent introduction to machinery diagnostics topics and serving as a handy multi-media format "encyclopedia," ideal for quick review.

Underscoring our commitment to this type of training and the convenience it offers our customers, we are expanding our selection of available cbts. In 2006, you can look forward to a cbt covering our new 1900/65 monitoring system as well as a cbt specifically for reciprocating compressor machinery diagnostics. You can learn more about our cbts by perusing the 2006 Training Schedule, available online at www.gepower.com/training and then using the link for "Bently Nevada Training." You may also request a printed version by using the Reader Service Card attached to this issue of ORBIT.



2006 Training Schedule

To help you assess your training needs, create a training plan, and fund your 2006 training budget accordingly, we're pleased to offer our Training Schedule for the upcoming calendar year several months sooner than in years past. It outlines our multi-track curriculum for understanding and using condition monitoring data and instrumentation, tailored to your specific job functions and interests. In 2006, we'll be offering more than 200 training sessions at our numerous global training centers, helping ensure that you can find a convenient date and location, no matter what continent you are on. You can access and download our 2006 Training Schedule online at www.gepower.com/training, following the link for "Bently Nevada Training." You may also request a printed version by using the Reader Service Card attached to this issue of ORBIT.



Reliability Workshops

Reliability is an essential element of running an enterprise competitively. Unfortunately, a focus on just implementing the right methodology or technology can doom a program to failure before it ever gets off the ground – either due to a lack of resources or the inability to change an organizational culture that views reliability as merely the latest fad or initiative.

We're now pleased to offer two different workshops, designed to help your facility understand – and embrace – not just the concept of reliability, but the tangible aspects of what it can do for you. For those specifically tasked with justifying and communicating reliability improvement initiatives to management, we offer the **Business Case for Reliability Workshop**. It equips participants with the knowledge and tools they need to develop and articulate the economic value of improved reliability. Consisting of equal parts discussion and activity-focused learning, participants use a database of reliability statistics from hundreds of facilities to benchmark their own facility. Using special calculation tools, participants then learn how to develop tangible ROI estimates.

Those tasked with the day-to-day activities associated with a reliability program will benefit from another of our workshops – the **Reliability Process Workshop**. Research shows that people are often resistant to ideas and objec-



tives that seem nebulous. Only when they can "see" and "feel" the objective can they fully internalize reliability goals and begin changing the way they work. Our Reliability Process Workshop uses an innovative simulation that's both fun and instructive. It has been employed successfully by numerous Fortune 500 companies, teaching participants to "follow the money" in moving from reactive to proactive reliability strategies, and furthering their understanding of the business issues that reliability impacts. You'll find the workshop is invaluable in obtaining genuine "buy in" from all the stakeholders in your organization.

Learn more about these new workshops in our informative brochures. Go to www.gepower.com/orbit, use the menu option "obtain literature," and select the 3rd Quarter 2005 issue from the drop-down list. There, you can download electronic copies or request printed copies. You may also obtain literature using the printed Reader Service Card attached to this issue of ORBIT. ☐

